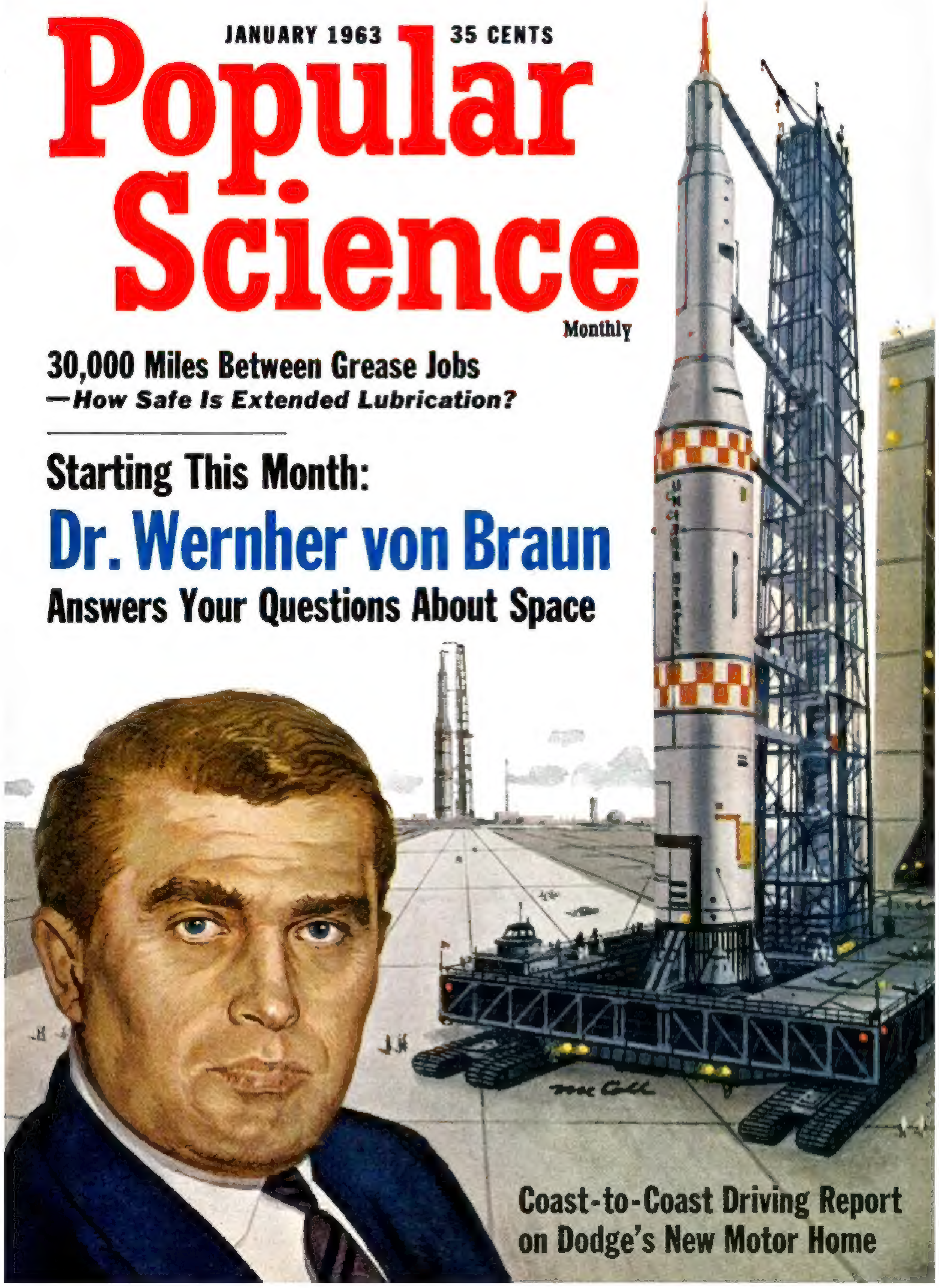
Popular Science

Monthly

Wernher von Braun

Wernher von Braun articles
published in Popular Science magazine
from December 1962 to September 1976



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Inside Our First Space Station

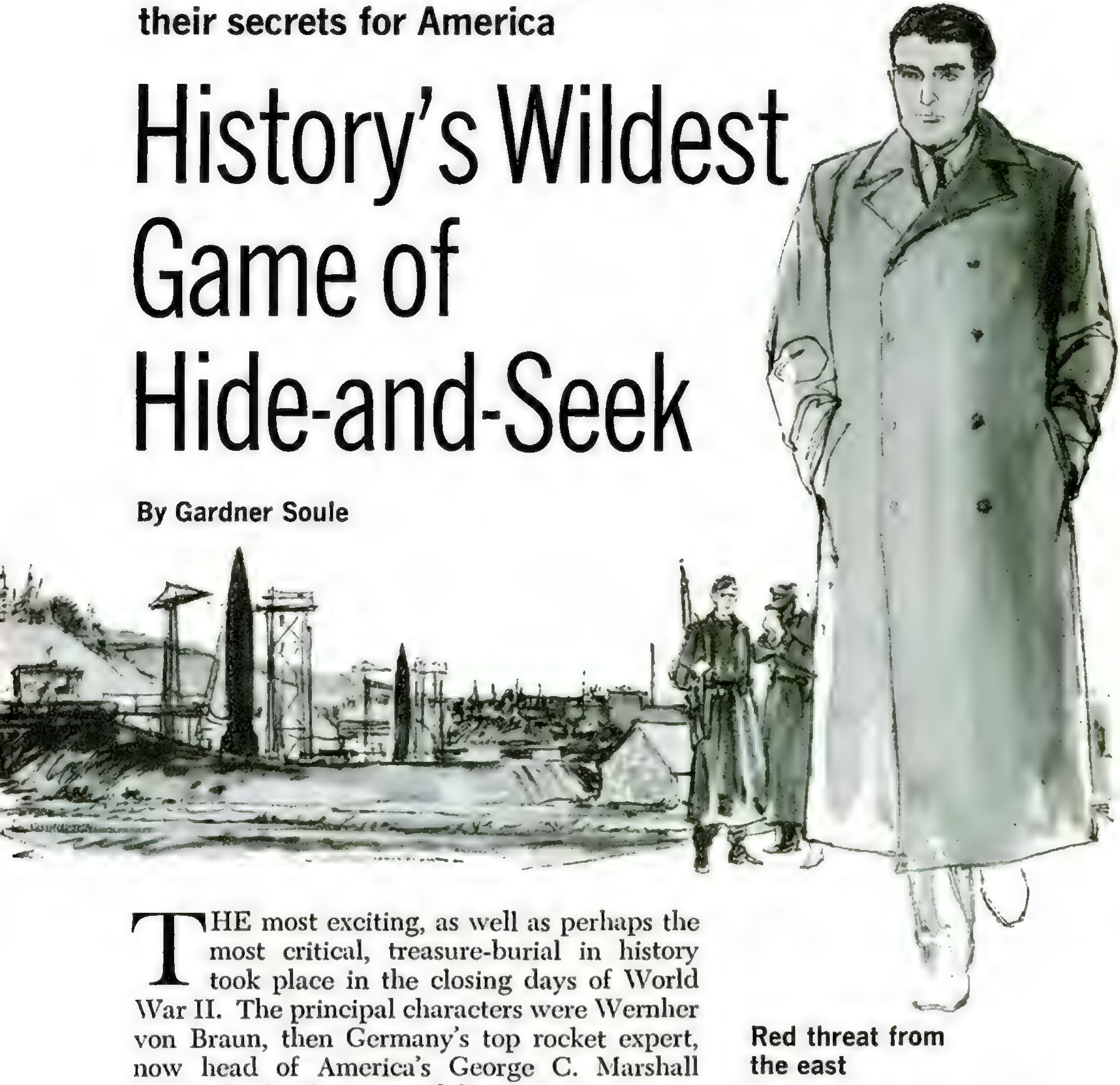
Extra: *First Time Ever in a Magazine!* **TRY-IT-YOURSELF TEACHING-MACHINE LESSON**

Car Features: *How to Install a Stick Shift—Transistor Ignition—Positive Crankcase Ventilation*

How the German rocket experts saved their secrets for America

History's Wildest Game of Hide-and-Seek

By Gardner Soule



THE most exciting, as well as perhaps the most critical, treasure-burial in history took place in the closing days of World War II. The principal characters were Wernher von Braun, then Germany's top rocket expert, now head of America's George C. Marshall Space Flight Center, and his assistant, Dieter Huzel, now with the Rocketdyne Company.

As the Russians closed in from the east on Peenemünde, Germany's rocket center on an island in the Baltic, the Germans moved their key personnel—and their tons of records—south to Bleicherode. Then the U.S. Army approached from the west. Who would get the records and the scientists—the Russians or the Americans?

Fortunately, *we* did. Turn the page to see how, according to Huzel's eye-witness account, it all happened.

From the book Peenemünde to Canaveral, *by Dieter K. Huzel.*

Red threat from the east

1. On March 12, 1945, with the Russian army at Swinemünde, only 50 miles away, the world's greatest rocket base went into a frenzy of evacuation activity. By truck and railroad, men streamed south. With the rocketmen went their records—top-secret research results that, at the time, were unique in the world. The plan was to set up the base again at Bleicherode, southwest of Berlin. The Germans would not admit that the war was lost.

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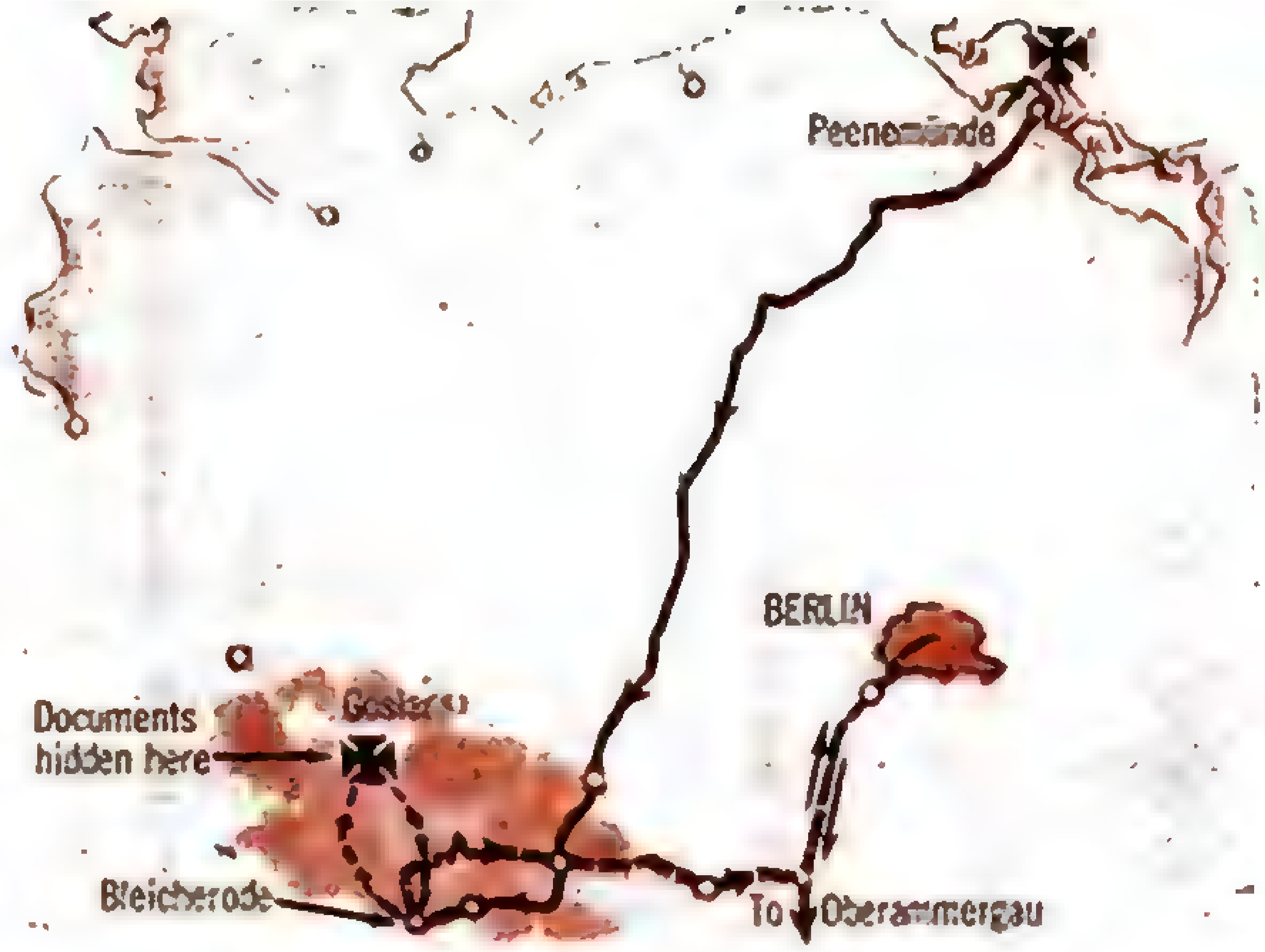
Ghost town in the moonlight

2. Dieter Huzel, an engineer who worked on all phases of the German rocket effort, was one of the last to leave Peenemünde. "I strolled down the street," he writes. "The moon, just past full, shimmered down between the rows of quiet, deserted buildings. There were a few traces of light . . . I thought how peaceful it was." Next morning Huzel went south by car. Trees along the highway had been chopped down so they could be pulled across the road.



U.S. tanks approach

3. Huzel reached Bleicherode by the route shown above. On Easter Sunday, word came that U.S. tanks had been spotted 12 miles away. The Germans began a frantic effort to hide some of the most valuable papers in history. Von Braun, his arm broken in an auto crash, turned the job over to Huzel. Handing his assistant a safe-conduct pass, von Braun said, "There is little I . . . can recommend to you on where to hide the documents. You're on your own."

"Maybe there is something"

6. Desperate—hearing machine-gun fire now in the distance—Huzel raced his little car over twisting mountain roads toward Goslar. There the man in charge was uncooperative at first. Huzel exploded: "Here I stand, with the most important documents in Germany! And I can't even find a place to put them." The man reconsidered. "Wait a minute . . . maybe there is something." He guided Huzel to an abandoned mine—complete with a heavy, ironclad door.

Found: a rock-hewn safe deposit

7. "It's ideal—it couldn't be better," said Huzel. Hurrying back to his trucks, he gave his orders: to drive to the mine one by one, during the night. All the men except the drivers were locked inside the trucks so they wouldn't know the location of the hiding place. Unloading at the mine, the men had a small electric locomotive and flatcars to help. Even then, the ton weight of the safe brought weary curses. The job took until the following noon.

Special! Starting Next Month:

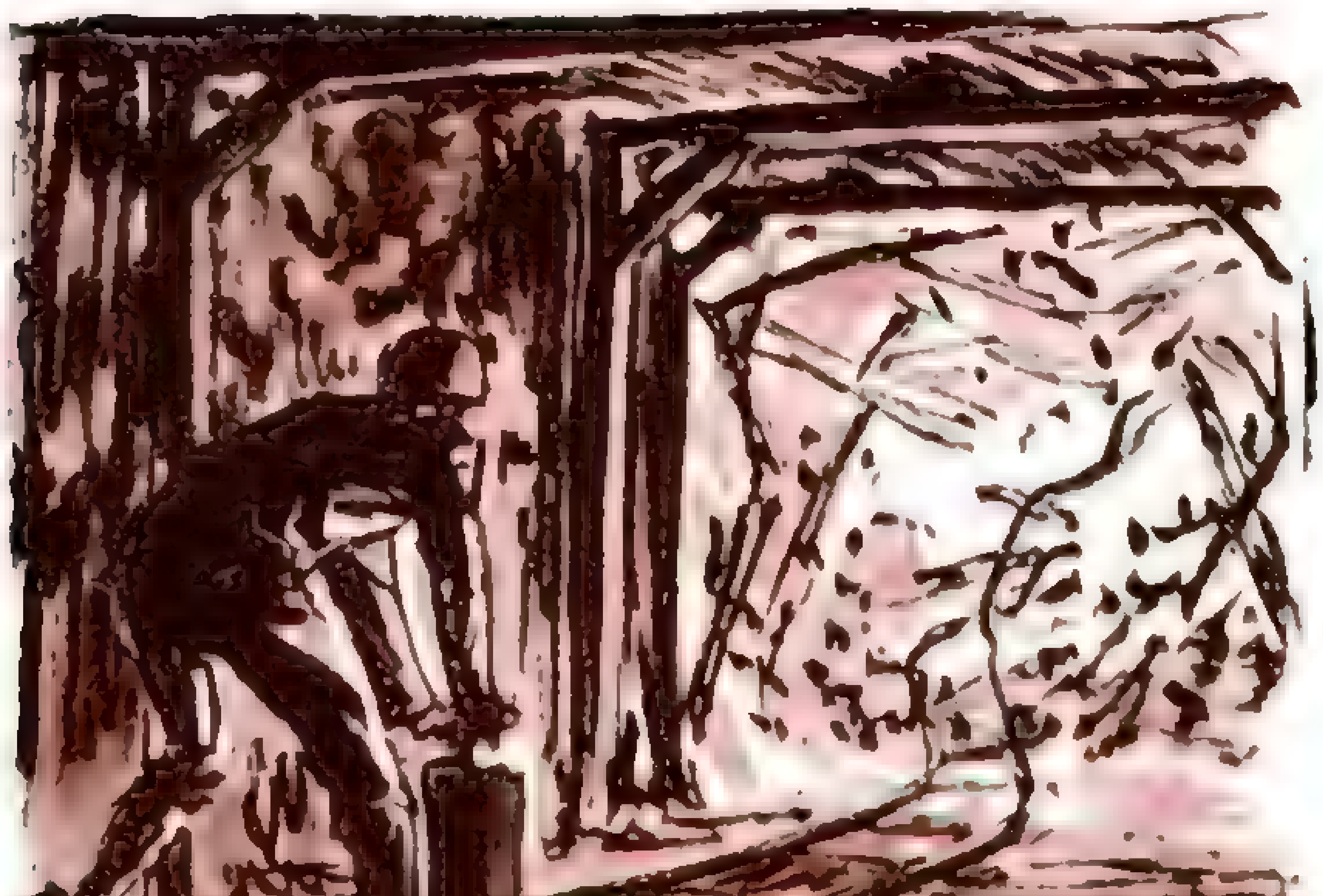
Dr. Wernher von Braun, world's leading rocket expert, will answer

The big blueprint move begins

4. Huzel commandeered ten men, three three-ton panel trucks, two trailers. Everyone was ordered to package the precious papers in small bundles. Huzel's men rushed about collecting the bundles—building up an astounding mountain of paper. With the trucks ready to go, it was found that one department (aft-end and rudder design) had its blueprints in small packages, all right, but locked in a huge, one-ton safe. The whole crew worked to get it loaded.

Enemy planes appear

5. As the truck caravan hurtled along secondary roads, Allied fighters flashed by overhead. When a lookout on the fender of the lead truck shouted a warning, the trucks took cover under trees. Looking for an abandoned mine as a cache, Huzel drove ahead to Clausthal, in the German mining district. He found an old man apparently in charge and asked where he might hide his treasure. "I am very sorry," the old man told him. "Try our suboffice in Goslar."



The paper treasure is buried

8. Next day, the mine gallery leading to the storeroom was dynamited, partially covering the big door leading to the hoard of rocket information. Events from then on, says Huzel, "assume a nightmare quality in my memory." Detouring back to Berlin by truck and bicycle, he reached the bombed-out city at one a.m. There he picked up his fiancée and fled south by truck. At Oberammergau, on the Austrian border, he caught up with Wernher von Braun.

Happy ending—for the U.S.

9. With the Russians pressing from the east, von Braun, Huzel, and five other German rocketmen drove to the U.S. lines and surrendered. Later, all were cleared to continue their work in the United States. Back at the mine, near Goslar, U.S. troops dug up the buried bonanza of rocket information. Thanks to von Braun, Huzel, and their men, who had moved west—not east—America, not Russia, would have the plans and blueprints of Peenemünde. ■■

1963

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Popular Science

Monthly

30,000 Miles Between Grease Jobs
—How Safe Is Extended Lubrication?

Starting This Month:
Dr. Wernher von Braun
Answers Your Questions About Space

Coast-to-Coast Driving Report on Dodge's New Motor Home

Popular Science Monthly

Our Most Important Announcement in 91 Years

BEFORE this decade is out, the President of the United States has promised, we shall have placed an American on the moon. The man in charge of the big rockets for this job is Wernher von Braun.

The announcement that Dr. von Braun will become a regular contributor to POPULAR SCIENCE is the proudest statement this magazine has made in the 91 years it has been reporting the progress of science.

Now director of the National Aeronautics and Space Administration's George C. Marshall Space Flight Center at Huntsville, Ala., Dr. von Braun was named technical director of the Rocket Development Center at Peenemünde, Germany, in 1937, at the age of 25. Under his direction, Peenemünde developed the liquid-fuel V-2.

In September, 1945, Dr. von Braun and more than a hundred associates were brought to the United States to continue their rocket experiments at Fort Bliss, Tex. Most of them moved to Huntsville in 1950. There they have been credited with such achievements as the launching of the first U. S. satellite, Explorer I, and the suborbital flights of Astronauts Shepard and Grissom, whose Mercury capsules were launched by a modified Redstone, our first big ballistic rocket.

Born in Wirsitz, Germany, in 1912, Dr. von Braun studied engineering in Germany and Switzerland, and was awarded a Ph.D. in physics in 1934 from the University of Berlin for a thesis on liquid-fuel rockets. He became an American citizen in 1955.

Robert P. Crossley
EDITOR

Wernher von Braun Answers Your Questions About Space

Why I am writing for Popular Science

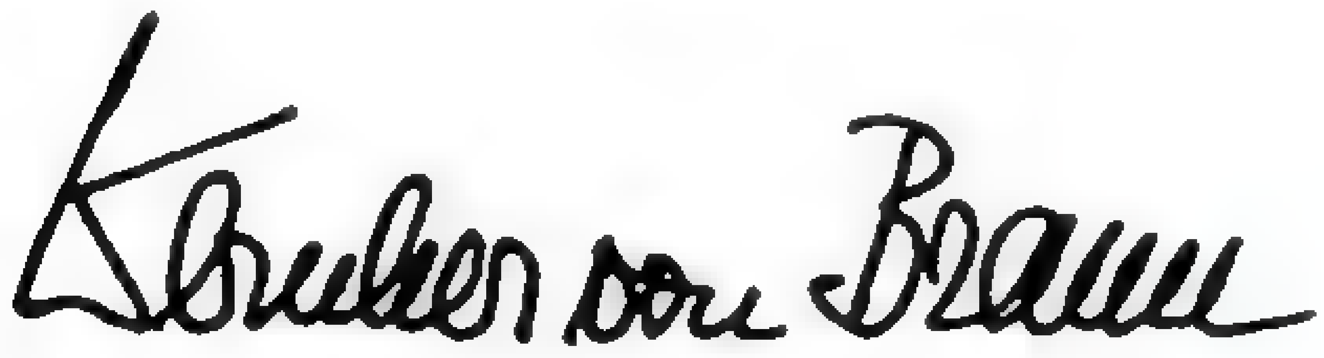
IF MY daily mail is a suitable yardstick, space science is a popular science indeed. I would not be able to get any other work done were I to try to answer systematically all those questions that find their way to my desk.

POPULAR SCIENCE'S invitation to write a monthly column on my favorite subject was thus received as both challenge and relief.

Challenge, because it always intrigues me to reduce a complex problem to terms that (I hope) anyone can understand. Relief, because I am frequently bothered by a bad conscience for not having replied to some of the most enthusiastic, inquisitive, curious, and penetrating letters.

Space science isn't like geography, or astronomy, or physics, or chemistry, or medicine. It is a little bit of all of them and more. That is what makes it so fascinating.

But it is this kaleidoscopic aspect of space science that makes it almost impossible to "organize" a monthly column such as this. Mr. Crossley and I have therefore agreed not even to try to arrange the questions and answers in any systematic way. If the result is a bit disjointed, it should at least be colorful.



How do you steer a rocket?

Q ***How are large rockets steered during powered flight?***

A All methods have one principle in common: The rocket exhaust is deflected in a controlled fashion.

For a rocket to fly straight, the force of its thrust must be so aligned as to point to the rocket's center of gravity. If the thrust force F is out of alignment and passes the center of gravity at a distance L, a turning moment will result that is equal to $F \times L$. A large rocket is steered by shifting this turning moment to the right and left (controlling yaw), or up and down (controlling pitch), depending on which way we want it to turn.

The force of a rocket's thrust is always parallel to that of the flow of exhaust gas, but acts in the opposite direction. In a liquid-propellant rocket, the combustion chamber with the exhaust nozzle is usually swiveled to and fro like the outboard motor of a small boat. The swiveling forces are provided by hydraulic actuators (oil-driven pistons) which are controlled by electrical signals from the rocket's control computer.

Older types of liquid-fuel rockets were often controlled by jet vanes. Usually there were four relatively small rudders of graphite, tungsten, or an ablative material—one whose expendable outer surface is allowed to char or volatilize—that were immersed in the main jet and rotated by electric actuators. Jet vanes do not deflect the entire jet but only part of it. The effect of a jet vane can be compared with that of a rudder located in the propeller down-wash of a larger inboard motorboat.

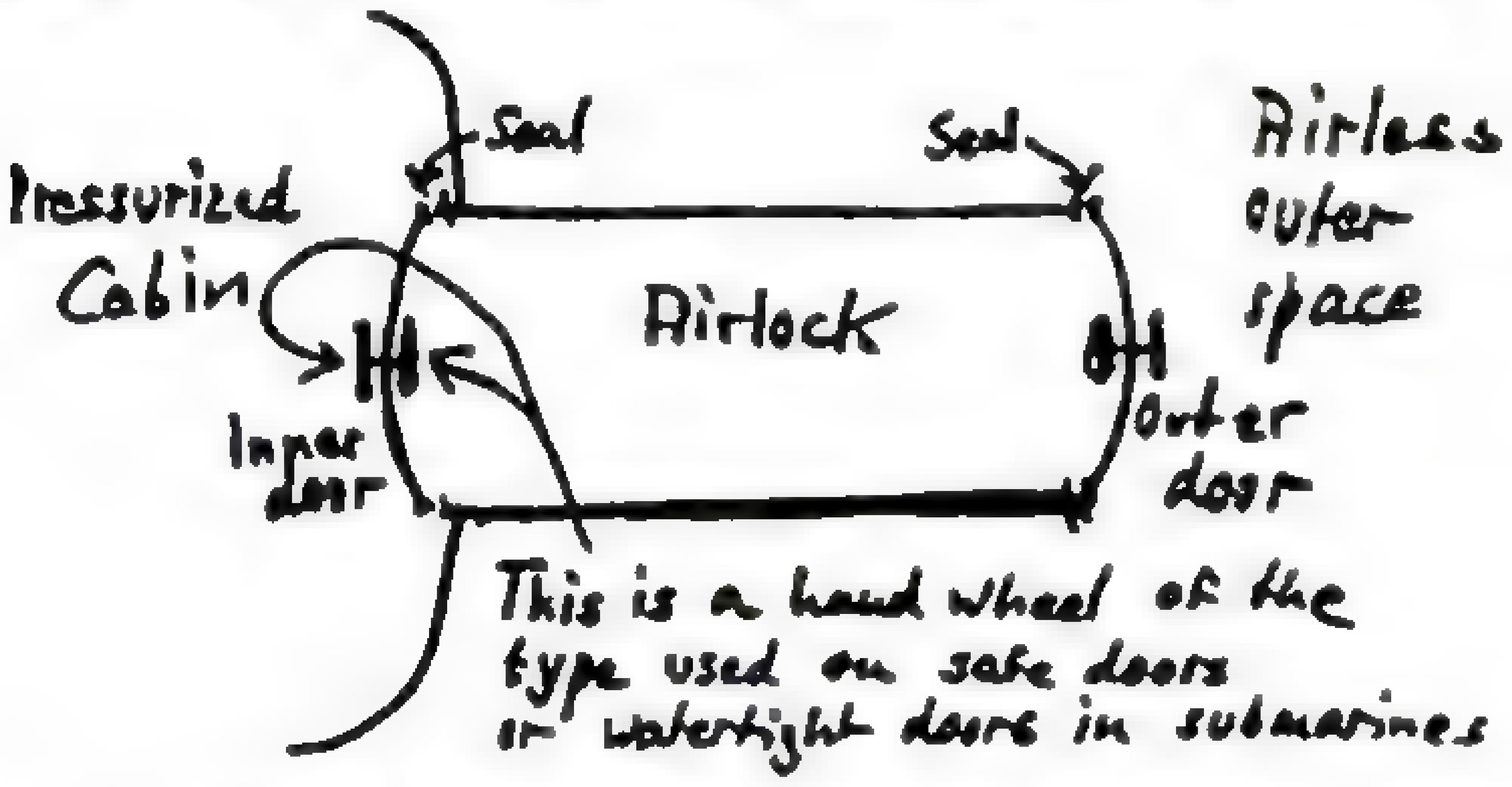
Steering solid-fuel rockets

Unlike liquid-fuel rockets, solid rockets do not have separate thrust chambers. In a solid rocket the basic airframe serves simultaneously as propellant-storage container and thrust chamber, and swiveling the thrust chamber would not be feasible. For this reason designers of

solid rockets have developed deflectable exhaust nozzles. Often a single solid rocket discharges its exhaust gas through four parallel-mounted swivel nozzles, permitting complete three-dimensional control in the up-and-down (pitch), the right-and-left (yaw), and the rotational (roll) directions.

Q ***How does an astronaut enter or leave his pressurized crew compartment in airless outer space?***

A By means of an air lock. This is a sealed compartment with access through two airtight doors, one from the pressurized cabin, one from the outside.



When leaving the cabin, the astronaut, clad in his pressurized space suit, enters the air lock, closing the inner door behind him. He now depressurizes the lock either by venting the air to the outside or by pumping it back into the cabin.

Once this is done, the pressure in the air lock is down to zero and equal to that of outer space. He may now open the outer door and leave his spacecraft.

Returning, he enters the nonpressurized lock through the outer door, closes it, and repressurizes the lock by opening a valve connecting it with the pressurized cabin. After the pressures of cabin and lock have been equalized he may open the inner door and enter the cabin.

For outside inspection: an air lock

Air locks will be used in advanced spacecraft (such as Apollo) to enable astronauts to leave their pressurized cabin temporarily. This may be desirable for outside inspection, docking maneuvers, rescue operations, and for crew transfer into another vehicle such as the lunar-excursion "bug" designed for the letdown from lunar orbit to lunar surface.

Q ***Why is liquid hydrogen such a good rocket fuel?***

A There are two reasons. One is the high heat energy released by the combustion of hydrogen. The other, equally important but less obvious, is the low molecular weight of hydrogen and its combustion product, water vapor.

The exhaust velocity of a rocket engine is the best yardstick of its fuel economy. Each gas molecule spurting from a rocket motor's exhaust nozzle can be looked upon as a tiny bullet fired from a gun. The higher the muzzle velocity, the more recoil will be exerted on the gun barrel. As the thrust of a rocket motor is made up of the total of all the little recoils produced by millions of molecule bullets, and the exhaust gas is produced by burning fuel, it follows that the higher the exhaust velocity with a given amount of fuel, the greater will be the rocket motor's thrust.

For high velocity: hydrogen

The exhaust nozzle of a rocket motor can be looked upon as a device that orients the all-directional movement of the gas molecules in the combustion chamber into one predominant direction. The exhaust velocity is, therefore, directly related to the velocity at which the gases whirl around in the chamber immediately after combustion but prior to entering the exhaust nozzle.

Now a fundamental law of physics states that *at a given temperature the average kinetic energy of the whirling molecules of any two gases must be the same.* The kinetic energy, or energy of motion of a body, depends on two factors: its weight (or mass) and its speed. This means that in order for a light and a heavy body to have the same kinetic energy, the light one must be faster. It

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follows that, for a given combustion temperature in a rocket engine, the propellant combination that produces lighter exhaust products will also produce a higher exhaust velocity.

Of course, a high combustion energy is needed to obtain a high combustion temperature. The combustion of hydrogen is one of the most powerful reactions known in chemistry. But, as we have seen, a light combustion product with a low average molecular weight is equally important. Hydrogen, with a molecular weight of only 2, is the lightest gas in existence. Even its combustion product, water vapor, resulting from reaction between two hydrogen atoms and one oxygen atom, has a molecular weight of only 18, which is quite low compared with that of combustion products of other fuels. Moreover, rocket engines using liquid hydrogen as fuel and liquid oxygen as oxidizer operate at maximum efficiency when running at a fuel-rich mixture. This means there are more hydrogen atoms around than there are oxygen atoms available with which they could react. The exhaust jet of such a rocket engine is therefore composed of a mixture of water vapor and unburned hydrogen, with a molecular weight somewhere between 18 and 2. It is because of these advantages that rocket engineers put great faith in liquid hydrogen.

Q ***Is the moon a dead world?***

A It is certain that the conditions on the lunar surface are prohibitive for any kind of higher animal or plant life. It is not impossible, however, that soil bacteria might exist on the moon, and we have no way of knowing whether there are subterranean deposits of ice that might be capable of supporting certain low forms of growth.

Some lunar craters are the center point of raylike features. These light-colored bands, sometimes several hundred miles long, seem unaffected by terrain over which they pass. Astronomers conclude they are made by dust thrown up by volcanic explosions or by volcanic gases frozen to the lunar soil.

Q ***What are solar flares?***

A Although the sun seems never to change in appearance, it is actually subject to erratic behavior. Its surface may be perfectly clean today; a month later it may be covered with dark spots. Sun spots are an indication of activity that bears some resemblance to volcanic eruptions on earth. The difference between the two phenomena is that the gas expelled by the sun—predominantly hydrogen—is so hot that the hydrogen atom (consisting of a proton and an orbital electron) is deprived of its electron. As a result, the solar gasburst, or flare, consists of protons or electrons.

Under "quiet" conditions, there is a more or less steady flow of these particles, called "solar wind." This flow travels all the way from the sun to the earth and beyond. During average solar eruptions the density of this flow increases a hundred-fold or more, and the velocity at which the particles reach the earth is also markedly higher. Once a year or so the eruption of a gigantic flare is observed, with particle densities and speeds far exceeding those in normal flares.

For manned space flight, only these giant flares are considered hazardous. A program to predict such flares has been initiated, and it is planned to time short trips (such as round trips to the moon) so that they won't coincide with the superflares. On long interplanetary space voyages it may be necessary to take along "storm cellars," into which the crews could withdraw during the hours of peak intensity of the flare. ■ ■

Dr. von Braun will consider answering questions from readers of Popular Science in the magazine, but he cannot undertake to answer each one by mail. Letters to him should be addressed in care of Popular Science, 355 Lexington Ave., New York 17, N. Y.

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Popular Science

Monthly

Answers to Your Space Questions by Wernher von Braun

How to do lathework on a table saw

FIRST LOOK AT '$63\frac{1}{2}$ CARS

Detroit Goes Back to the Races

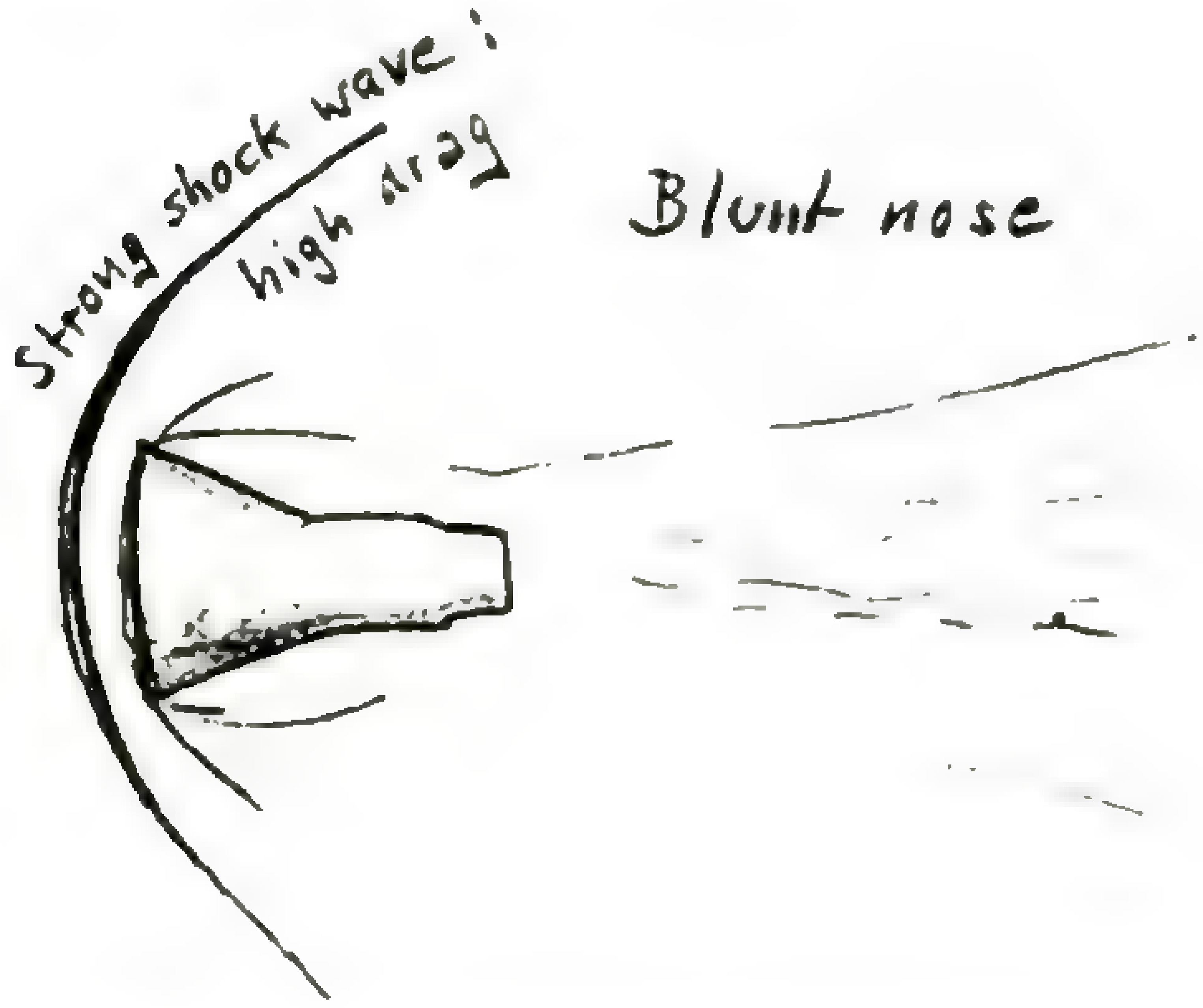
To see how this picture turned out, see page 61...

NEW! All About

More Answers to Your Questions About Space by Dr. Wernher von Braun

Q ***Why has the Mercury capsule a blunt nose?***

A For an orbiting spacecraft to return to the earth's surface, its initial velocity must be reduced to zero. To provide the entire retardation energy with retrorockets is unattractive; it would call for a rocket-propulsion system of about the same power and propellant consumption as the one used to carry the spacecraft into orbit in the first place. For this reason, retrorockets are employed only for the limited task of pushing the spacecraft's orbital path back into the atmosphere. The bulk of the braking action



is provided by the ensuing aerodynamic drag.

The drag is produced by air compression and air friction. Both generate heat. Suppose the kinetic energy of an iron ball, entering the atmosphere at an orbital speed of 25,600 feet per second, was completely converted into heat and all that heat was transferred back into the ball. It would never reach the ground, because there would be enough heat to melt 35 iron balls!

For successful re-entry it is therefore essential that only a small fraction of the total heat generated during aerodynamic deceleration be absorbed by the spacecraft. The most effective mechanism to carry energy away from the spacecraft and into the surrounding air is a shock wave. You may have witnessed the havoc caused to adjacent moorings by a large boat moving through a narrow channel at excessive speed. It demonstrates vividly that a very substantial portion of the boat's horsepower is carried away by the bow wave.

The blunter the bow, the stronger the wave. This is just as true for a spacecraft returning at hypersonic speeds.

We see, therefore, that the Mercury capsule has a blunt nose in order to *minimize* the heat absorbed by the spacecraft's structure, and to *maximize* the heat carried away by the shock wave.

What about supersonic aircraft?

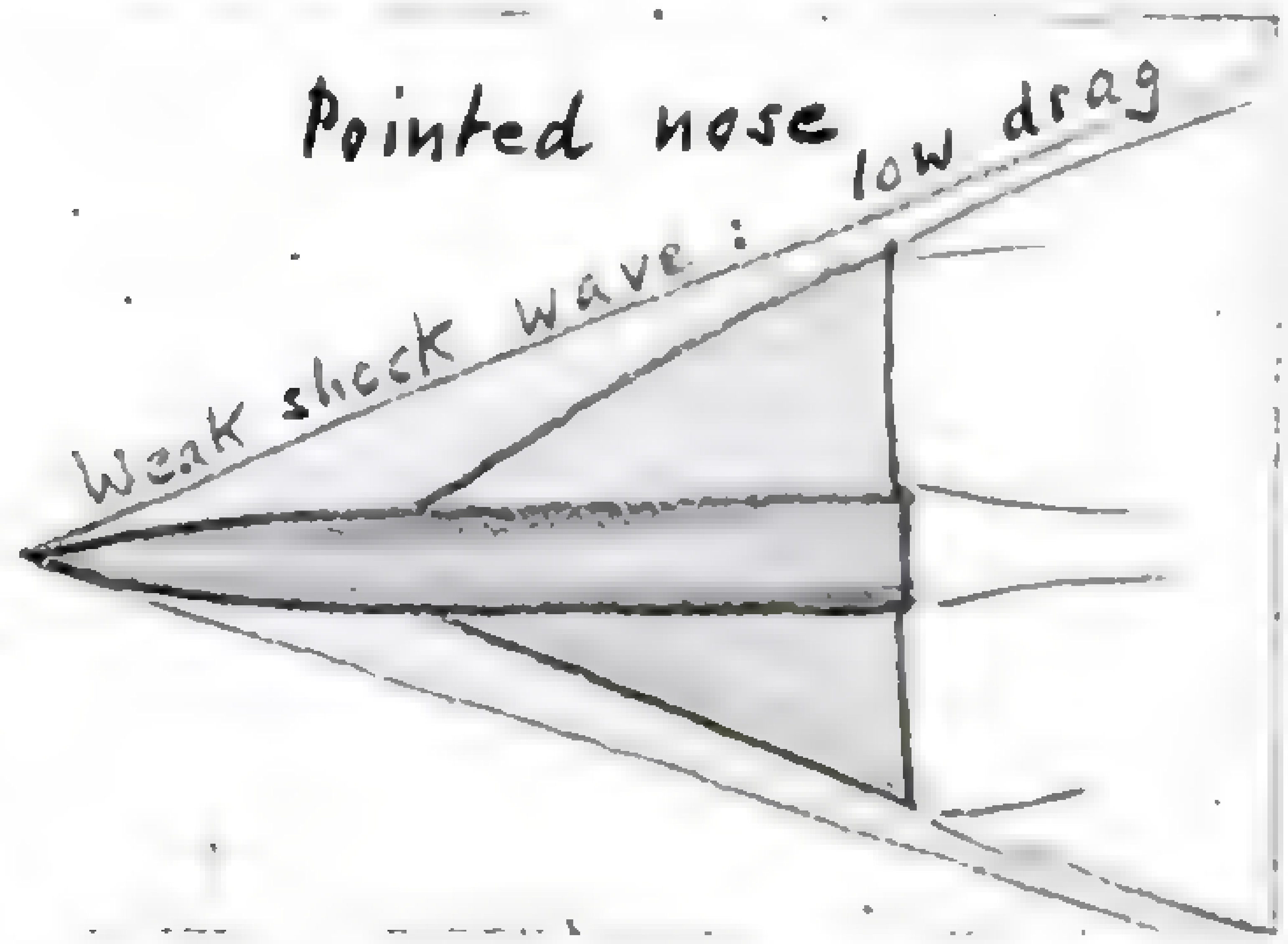
Supersonic airplanes are needle-nosed to keep down aerodynamic drag. This is necessary when the designer has the

Co-chairman of a $100-a-plate "Night of Exploration" dinner in New York, November 2, Dr. Wernher von Braun presents a scroll on behalf of the Explorers Club to Astronaut Walter M. Schirra Jr. Sharing the head table with Dr. von Braun, Director of the George C. Marshall Space Flight Center, were such notables as Sir Edmund Hillary, conqueror of Mt. Everest; General James A. Doolittle; Lowell Thomas; James E. Webb, Director of the National Aeronautics and Space Administration; and Colonel Bernt Balchen, first man to pilot a plane across both poles.

task of reaching ever-increasing speeds with the limited engine power at his disposal.

Aerodynamic heating, on the other hand, is not yet a very serious problem at the speeds of present-day supersonic aircraft, operating at Mach 2 or 3.

An orbiting spacecraft such as the Mercury capsule is boosted into space by a powerful rocket that rises vertically. Its flight path begins to level off only after it has cleared the denser layers of



the atmosphere. Here, drag reduction during the ascent becomes a minor consideration. Re-entry from orbit, however, is commenced at Mach 25! During the blazing retardation maneuver that follows, the job of keeping the heat away from the capsule, and of dissipating as much of it as possible into the surrounding atmosphere, must be our first concern.

Q *How dense is the Martian atmosphere?*

A It's pretty thin, and its physical makeup is quite different from that of the atmospheric shell that surrounds the earth.

Before we discuss it further, let us see on what observations those conclusions are based.

All of the light coming from Mars is reflected sunlight. Part of that light, before reaching our eyes, has been reflected by the Martian surface and has thus penetrated the Martian atmosphere twice—on the way down and on the way back up. The rest has been reflected by Mars' atmosphere itself and thus has never reached the ground.

Figuring pressure at surface

A careful analysis of the sunlight reflected by Mars has led astronomers to conclude that the *mass* of a column of Martian atmosphere resting upon a square inch of the planet's surface amounts to about 22 percent of that of a comparable column of air on earth. Due to the much smaller size of the Red Planet, the gravitational pull at Mars' surface is only 38 percent of one "G" (the gravity to which we are accustomed on earth). Consequently, the surface *weight* of that column of Martian air is only $.38 \times .22 = .084$ of the weight of its terrestrial counterpart.

CONTINUED

Mars' atmosphere . . . and tying down a rocket

The atmospheric pressure at Mars' surface is the weight of that column of air. Since, on earth, sea-level pressure averages 29.92 inches of mercury, it follows that on Mars we may expect a surface atmospheric pressure of about $29.92 \times .084 = 2.5$ inches of mercury (or 85 millibars).

This is one-twelfth of the sea-level pressure on earth and about the same pressure that prevails 11 miles up in our stratosphere.

Atmosphere, though thin, goes high

However, as we rise from the Martian surface into this tenuous atmosphere, we find its pressure stratification quite different from that of the earth's air. This, again, is a direct result of Mars' feeble gravity, which simply fails to compress its atmosphere into as tight and compact a layer of gas as ours. In the earth's atmosphere we have to climb to an altitude of about 10 miles to experience a reduction of atmospheric pressure by a factor of 10—that is, from 29.92 inches to 2.992. (It is down to .299 inches at 20 miles, to .0299 at 30 miles, and so on.) In Mars' atmosphere, we would have to climb to an altitude of about 25 miles to experience a pressure drop to a tenth of the Martian surface pressure—from 2.5 inches to .25. We would have to ascend to 50 miles to get it down to .025 inches, and to 75 miles to reduce it to .0025.

This leads to an interesting conclusion: Although the surface pressure on Mars is only one-twelfth of our sea-level pressure, at altitudes above 19 miles the Martian atmosphere is actually *denser* than our own.

What astronauts can expect

This is of considerable practical importance for future voyages to Mars. Many important phenomena (aurora effects, airglow, ionization, meteorites) take place in the upper layers of a planetary atmosphere. Altitudes of clouds are directly related to the pressure stratification of the atmosphere. Generally speaking, we can say that in the Martian atmosphere, atmospheric phenomena can be expected to extend to much higher altitudes.

The first astronauts to enter the Martian atmosphere for a landing will feel its decelerating effect at altitudes where back on earth they orbited with no noticeable atmospheric drag.

Q ***How are large rockets prevented from taking off with inadequate thrust?***

A The rocket is tied to the launch platform by a multiple clamp-down mechanism, which is released only after there is clear evidence of adequate rocket-engine performance.

The technique of holding rockets down during thrust build-up was tried, off and on, during the early years of guided-missile development. It became standard procedure with the advent of multiengine rockets, because of the obvious hazards involved in a takeoff with one faulty or inoperative rocket engine.

In launching large multiengine rockets such as Atlas or Saturn, at least one characteristic indication of adequate engine performance (such as combustion-chamber pressure) is piped into the control room for all engines involved in the takeoft. The decision to release the clamp-down mechanism (commonly called the "tail grab") is made by the launch director on evidence that all engines are "in the green." In modern launch facilities the procedure is often automated; that is, the tail-grab signal is activated automatically when all engine read-outs are within pre-specified limits. All engines are shut off if this condition is not met within a few seconds. ■ ■

Dr. von Braun will consider answering questions from readers of POPULAR SCIENCE in the magazine, but he cannot undertake to answer each one by mail. Letters to him should be addressed in care of POPULAR SCIENCE, 355 Lexington Ave., New York 17, N. Y.

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Popular Science

Monthly

VEHICLE OF 500 USES

PSM SPOTLIGHT AWARD

p. 64

Amazing New Kind of Motor

Boats! Boats! Boats!

22 PAGES:

- How to get started in boating
- How to buy a used boat
- In color: How to outfit your new boat
- Specs on all outboard motors

Wernher von Braun Explains Nuclear Rockets

Dr. von Braun discussses space problems with Editor Bob Crossley on visit to POPULAR SCIENCE offices in New York.

Dr. Wernher von Braun Answers Your Questions About Nuclear Rockets

Q ***How will nuclear power be used for space flight?***

A Two different concepts are in the works: the nuclear blowdown rocket and the nuclear ion rocket.

The nuclear blowdown rocket can be designed, just as a chemical rocket can be, for any amount of thrust. It can produce as much thrust as the best hydrogen-oxygen combustion rockets, for twice as long, with the same total propellant consumption. In other words, it is about twice as efficient in use of propellant. It works not only in outer space, but also within the atmosphere.

The nuclear ion rocket yields only feeble thrust, and does not work within the atmosphere. But it can exert its weak thrust for long periods, enabling a space vehicle gradually to build up enormous speed. It is about 10 times as efficient as a nuclear blowdown rocket.

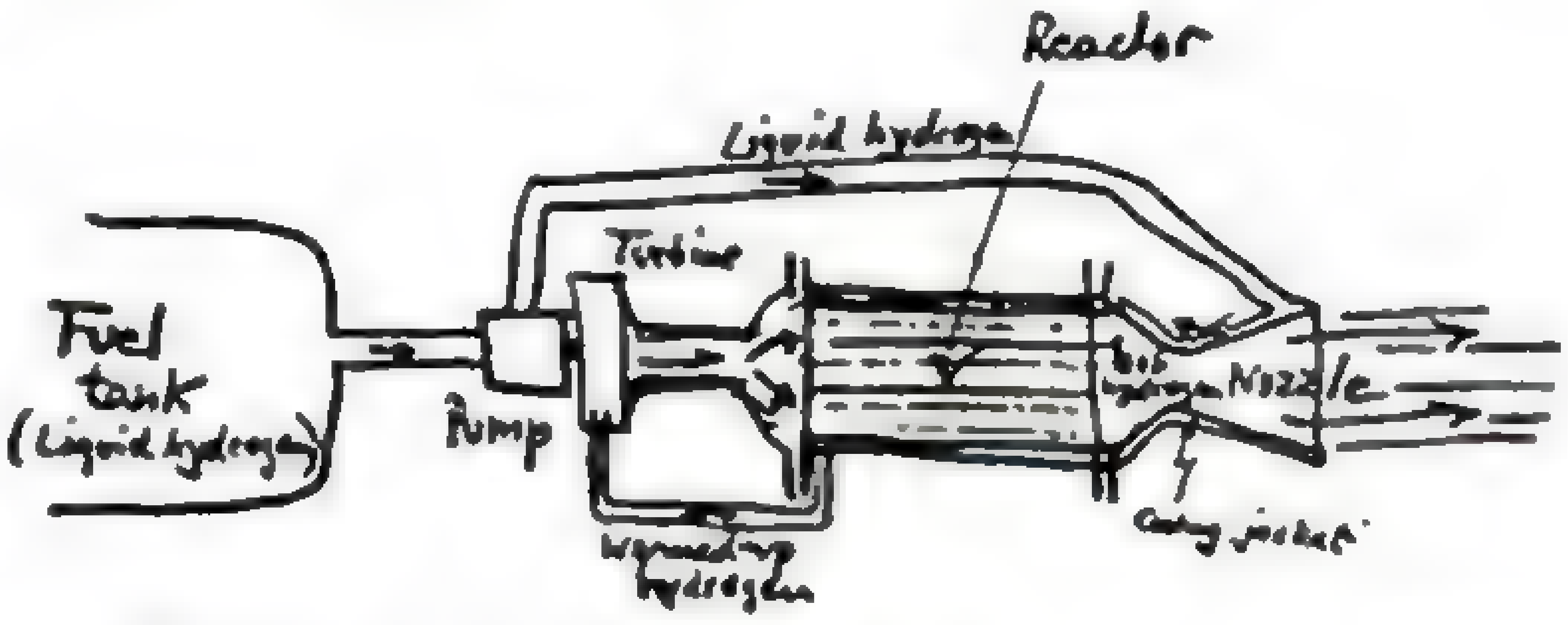
Q ***Will these different nuclear rockets serve different purposes?***

A Yes. A nuclear blowdown rocket has the most promise as an upper stage of a very large, chemically boosted space vehicle. Such a craft could provide a highly economical round-trip transportation system between Earth and Moon.

The nuclear ion rocket seems destined for use as "cruise power" for interplanetary travel. It offers a vast increase in payload for planetary exploration, without recourse to excessively large and costly earth-launched rockets.

Q ***How does a blowdown rocket work?***

A In essence the nuclear blowdown rocket is a reactor, perforated by narrow channels into which liquid hydrogen is pumped. When control rods are withdrawn, a neutron chain reaction makes the reactor white-hot. The control rods' action holds this temperature level.

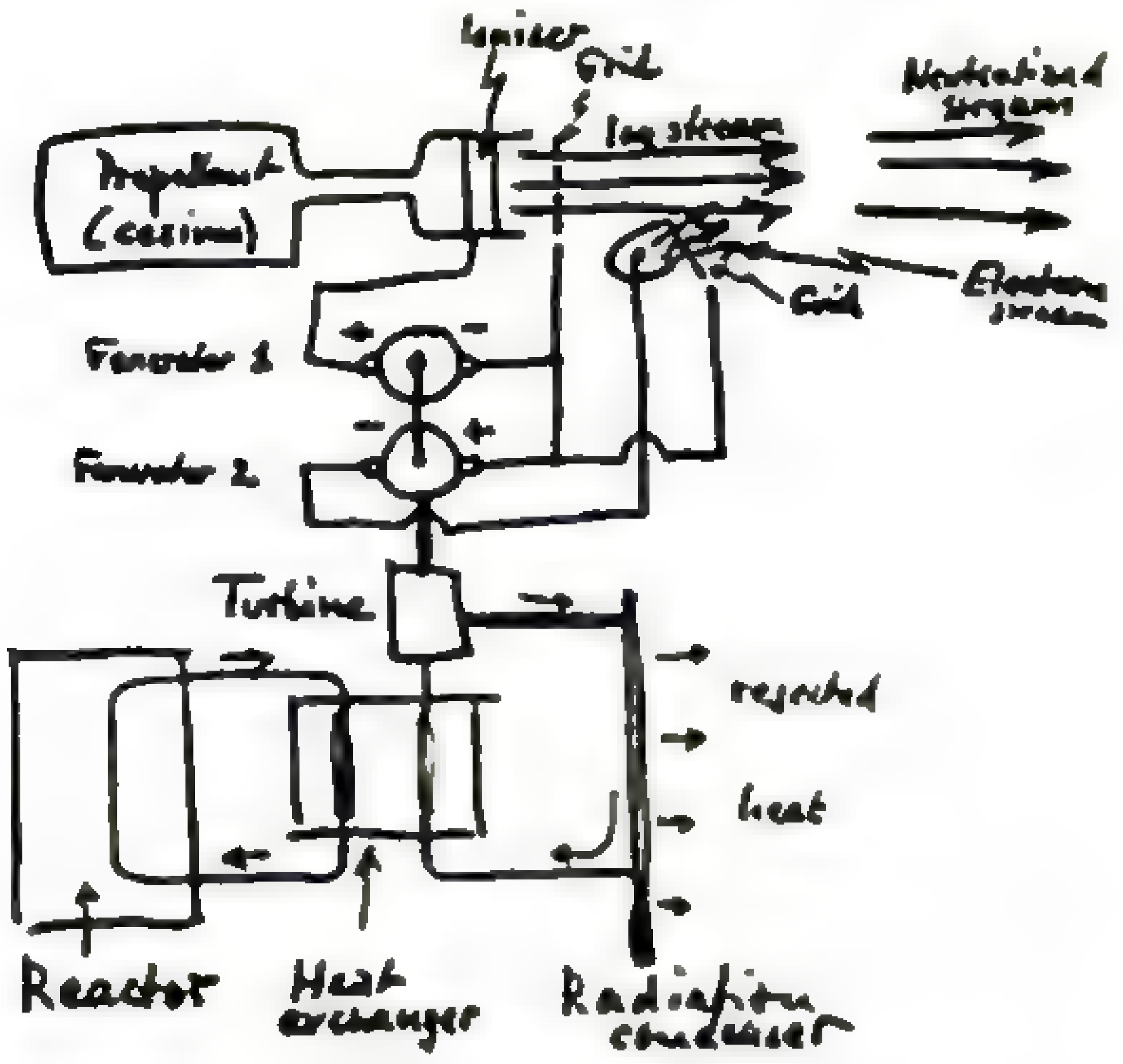


Fed by a turbine-driven pump, liquid hydrogen flows first through passages for cooling the exhaust nozzle and the reactor's pressure vessel. Still pretty cold but already gasified, it enters the reactor. In the reactor's tubular channels, the hydrogen is heated to a temperature of several thousand degrees. Then it spurts from the exhaust nozzle.

Because of the very low molecular weight of hydrogen, exhaust velocity is very high, and this means a most economical use of propellant.

Q ***What is the principle of an ion rocket?***

A In this type, the reactor's nuclear energy is first converted into electrical energy. That takes relatively heavy machinery, such as turbogenerators, heat exchangers, and radiation condensers.



In one ion-engine design, the easily liquefied metal, cesium (melting point, only 83 degrees F.), is pumped through a porous and incandescent tungsten plate called the "ionizer," from which it evaporates. As it does so, a negatively charged electron is stripped off the cesium atom. Originally electrically neutral, the atom now becomes a positively charged ion.

To a grid in front of the ionizer, a generator applies a negative voltage. Since unlike charges attract, the negatively charged grid accelerates the stream of vaporized, positively charged cesium ions—and hurls them into the vacuum of space beyond, at a speed of 60 to 100 miles per second. The thrust of an ion rocket comes from the reaction force on the grid.

Of course, if we kept expelling positive ions from a rocket ship, it would soon build up a powerful negative charge—and its attraction would prevent any more positive ions from escaping. But there is a simple remedy:

All we have to do is to take those negative electrons that were stripped from the cesium atoms—and, with a second generator, "pump" them into the stream of escaping ions. This neutralizes the ion jet (or "beam," as ion-rocket men call it), and the electrostatic balance of the ship is restored.

Obviously the power rating of the electrical conversion equipment must at least equal the power carried away in the beam. (Because of conversion losses, it must actually be greater.) So very substantial machinery is needed to produce even as little as a pound of thrust. Thus, aside from the fact that it wouldn't work in the atmosphere anyway, an ion rocket could never lift its own weight off the ground.

But in outer space, with zero gravity, we do not need a thrust exceeding the ship's weight. Apply only one pound of thrust to a five-ton rocket ship, for a whole week, and you build up a speed of more than 1,300 m.p.h.! The capability of such long-sustained thrust and unmatched fuel economy explains why ion propulsion is considered the key to manned interplanetary exploration.

Q ***What is an analog-digital conversion system?***

A Actually it is one of those wordy but fashionable space-age terms for an old idea.

There are two fundamentally different "modes" or ways of displaying data: the *analog* mode and the *digital* mode. The speedometer in your car employs the analog mode, because the angular deflection of the needle is analogous to the speed at which your car is traveling. But the odometer, whose set of jumping figures totals the mileage you have put on your car, uses the digital mode of display. It presents the mileage directly as a five- or six-digit number.

Acquiring many items of in-flight data simultaneously is of paramount importance for the development and operation of space rockets. All these data must be radioed down to the ground through telemetry links.

Now, many data are collected most easily in analog form, and need not be extremely accurate, anyway. For instance, the pressure in a rocket's propellant tank can be measured quite simply by a manometer, working on a variable resistor

[*Continued on page 198*]

[Continued from page 63]

(commonly called a potentiometer). The varying pressure then presents itself in the analogous form of a varying voltage, which can be radioed to earth.

Other data can be obtained most conveniently in digital form. For example, the speed of rotation of a rocket turbopump can be measured with a simple slip-ring contact, which feeds one electric pulse into the telemeter transmitter for every revolution of the pump shaft. It is easy to see that there will be no loss in accuracy whatever if, on the ground, the chain of incoming electric pulses drives a digital-display unit like the odometer in your car.

There is a third situation, however, and this is where analog-digital conversion systems come in: Suppose we want to telemeter to the ground with extreme accuracy, during flight, the steering movements of a hydraulic actuator that deflects a rocket engine. We could equip the piston of the actuator, just like that tank manometer, with a potentiometer and radio the resulting voltage changes to the ground. This, of course, would be an analog method. The accuracy attainable would be limited by the wire thickness of the potentiometer, and by inherent difficulties in telemetering voltage readings precisely.

Turning "analog" into "digital"

We can do better by converting the "analog" movement of the piston into a digital readout. For instance, we can rig up a system so that the piston, through a high gear ratio, will rotate a slip-ring contact like the one on the turbopump. Instead of a varying voltage, we now can radio a chain of discrete pulses to the ground—with a resulting gain in accuracy for the whole data-transmission system.

Probably the simplest analog-digital conversion system is your dial telephone. The angle between your finger and the stop, before you spin the dial, may be compared with an "analog" needle deflection we may want to transmit. But all the transmission lines ever see is a chain of electrical pulses containing the information in digital form.

Q ***Why are lunar and planetary rockets put in "parking orbits"?***

A From the point of view of celestial mechanics, a rocket could be launched

CONTINUED

from any point on earth *directly* to the moon or any planet. Placing the rocket temporarily in a parking orbit (around the earth), first, is solely for convenience in carrying out the operation. It greatly widens the "launch window," the time span during which the launch may be executed.

Take a launching from Cape Canaveral to the moon. The Cape whirls around the earth's axis once in 24 hours, while the moon orbits the earth about once a month. Hence the task of hitting the moon can be compared with that of shooting a running rabbit from a revolving merry-go-round. Your "firing window" is short—you can fire only during the brief interval when the rabbit is in sight. Next time around, your aim must change, because the rabbit has moved on.

Now, it is still a rather tricky business to get a complex multistage rocket off its launch pad at precisely the right instant. It would be very awkward indeed if the whole complicated set of earth-to-moon guidance instructions had to be changed, just because the zero time was missed by only a few seconds.

Where precise timing counts

From the vantage point of the lunar target, however, it can be seen that there is only one point of the trajectory at which precise timing is really critical. That is where the rocket enters its long, unpowered "transfer" path to the moon—the so-called "translunar injection point."

A parking orbit divides the earth-to-moon journey into two distinctly separate phases of powered flight: the launch-to-orbit portion and the orbit-to-lunar-injection part. The rocket's "stay time" in the parking orbit, until the right moment comes to start it on the second phase of its flight to the moon, may be a few minutes or several hours.

Thus a parking orbit provides desirable slack between the "flexible" or possibly unpredictable timing of the ground launching, and the "frozen" timing for translunar injection.

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Questions
About Inertial Guidance

Dr. von Braun watches a Juno II launching from Cape Canaveral blockhouse. In background is Dr. Kurt Debus, Launch Director at the Cape.

Dr. Wernher von Braun Answers Your Questions on Inertial Guidance

Q ***Why does a rocket need a guidance system?***

A To keep a rocket on its prescribed flight path despite disturbances by wind, or by slight deviations from the rocket's standard weight or performance, we must continuously generate and apply commands that correct its motion. We can take our choice of two guidance systems: remote control or inertial guidance.

Guidance commands may be generated by tracking the rocket with optical instruments, radar, or radio, and comparing the *actual* track with the *prescribed* flight path. A remote-control command passed on by radio instructs the speeding rocket to reduce any difference between "is" and "should be" to zero.

Such guidance systems, based on remote control by radio, have several basic drawbacks. For one, they are subject to intentional as well as unintended interference, which makes them particularly vulnerable in military operations. For space-flight operations, an even more serious drawback lies in the fact that it is impossible to maintain radio contact between ground station and rocket except along a line of sight between them. For economy in consumption of propellant, an orbital rocket must ascend to its orbit along a very shallow trajectory—and so the burn-out point of the last rocket stage is frequently well below the horizon of the launching site.

In deep-space missions, the rocket may stay in one or several "parking orbits," and must restart its engine at a very precise instant for the ensuing power maneuver that leads to injection into a trajectory to the moon or the target planet. The orbital restart point may be over Australia or the Pacific Ocean, while the launching was from Cape Canaveral, Fla. Radio-guidance schemes for such operations would involve a complicated globe-circling network.

An *inertial*-guidance system does away with all these communication difficulties by generating the guidance commands *on board the rocket*. Such a system is entirely self-contained.

Q ***What is the principle of inertial guidance?***

A The basic idea behind an inertial-guidance system for a rocket is to measure its accelerations in three "orthogonal" (mutually perpendicular) directions, such as up-and-down, right-and-left, fore-and-aft. The three accelerations then are "integrated," an operation that a following paragraph will make clear, to obtain the velocity in each direction. In turn, the three velocities are integrated to get the *displacement*, or distance traveled, in each direction. This answers the rocket's ever-repeated query, "Where am I?"

Knowing from an electronic memory where the rocket *ought* to be at any moment, and noting any deviation, the

CONTINUED

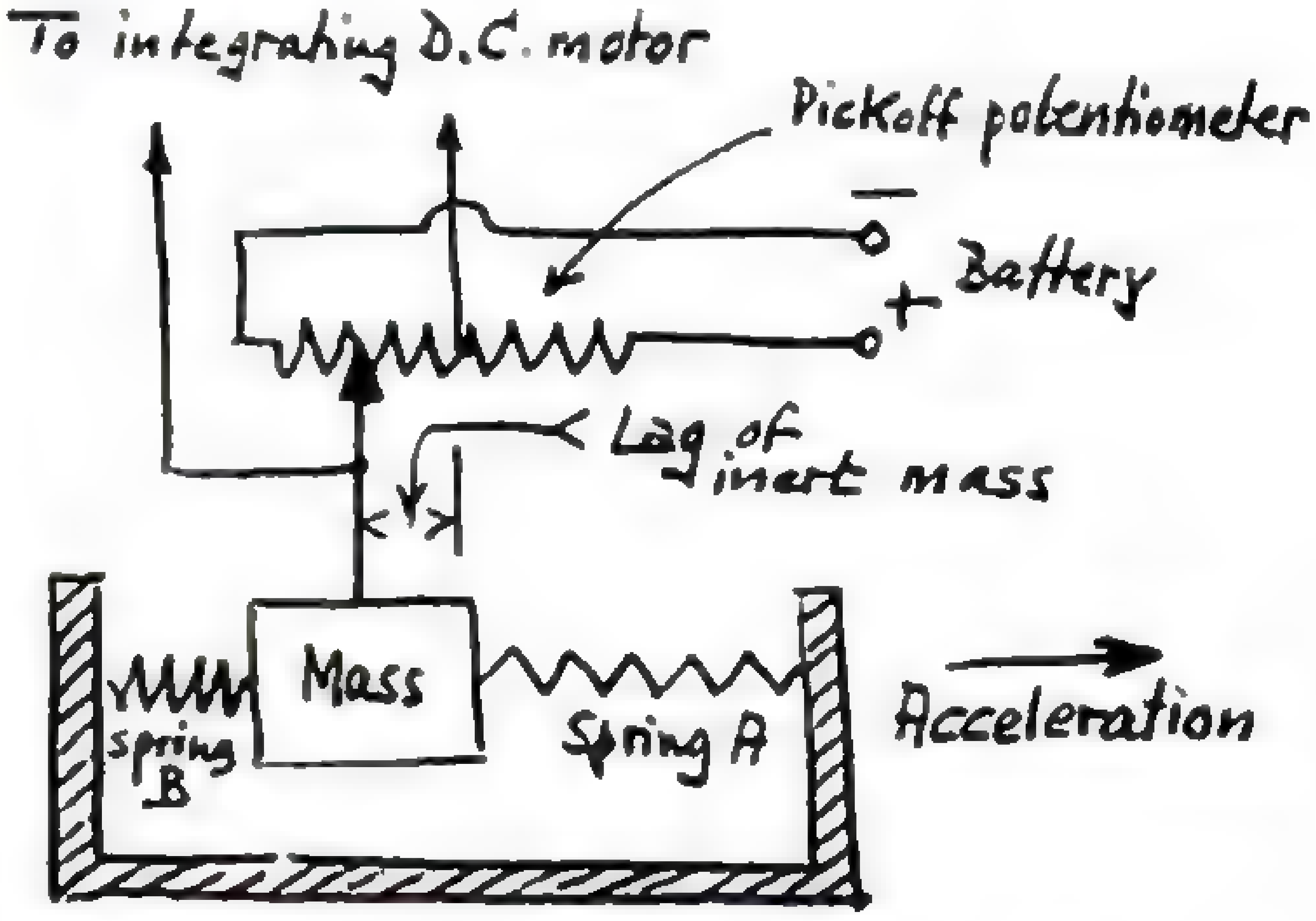
guidance system produces the needed commands to correct the flight path.

The heart of any inertial-guidance system is thus a set of three orthogonal accelerometers, to measure the three components of the rocket's acceleration.

Q ***How can you measure acceleration?***

A Acceleration is what sports-car drivers call "getaway." It manifests itself as a force that presses the driver against his seat back when he steps on the accelerator. This force is the result of his body's inertia, which resists the sudden change of pace—whether the car is accelerating from a standstill, or from 40 to 60 m.p.h. to pass a lumbering truck.

There are many types of accelerometers, but they all measure that "force against the seat back" due to the inher-



ent inertia of mass. The simplest is the spring-mass accelerometer in my sketch.

As the rocket accelerates in the direction shown by the arrow, the inertia of the mass causes it to lag behind, stretching spring A and compressing spring B. A sliding-contact variable resistor, labeled "pickoff potentiometer," produces a voltage that corresponds to the acceleration at any instant.

Q ***How are accelerations integrated?***

A The speedometer in our sports car clearly indicates that the velocity is increasing, second by second, as long as we feel that pressure against the seat

CONTINUED

back. Of course, the speedometer is rigged to the wheels and really tells how fast they're spinning. But we could build another speedometer around our spring-mass accelerometer:

Suppose we drive a little DC electric motor with the voltage from the accelerometer's pickoff potentiometer. The motor will spin as long as there is an acceleration, stop as soon as it ends.

The speed at which the motor's armature revolves corresponds to the voltage supplied by the pickoff potentiometer, which in turn corresponds to the acceleration. But the total number of turns that the armature makes, over a given period of time, corresponds to the velocity built up as a result of the acceleration during that same period.

Thus, all we have to do to get our accelerometer-driven speedometer is to attach an indicator needle to the armature of the little motor—over a high gear ratio, of course. Our new speedometer is the prototype of what guidance people call an "integrating accelerometer."

We could stick a second potentiometer on the needle axis of our new instrument, and drive a second electric motor with the voltage output. Since the picked-off voltage corresponds to the car's velocity, the second electric motor will spin at a rate corresponding to that velocity, and the total number of revolutions made by its armature will correspond to the distance traveled by the car. A needle attached to the second motor, again over a high gear ratio, will show the mileage covered—giving the same reading as the car's standard odometer. (The latter counts the total number of turns made by the wheels.) With the second electric motor we've performed the "second integration"—we have integrated velocity over time elapsed and found the distance traveled.

Q ***Is there more to designing a practical rocket guidance system?***

A Yes. The designer is confronted with two principal kinds of difficulties:

1. The rocket changes its attitude

CONTINUED

throughout the flight. At takeoff it stands upright. At injection into orbit it speeds along horizontally. Moreover, as it passes through the atmosphere, it is tossed around by turbulence and shifting wind, changing its attitude temporarily.

Our three orthogonal accelerometers must therefore be placed on a gyroscopically stabilized platform. However the rocket may turn and waver, the three accelerometers will now have and retain a fixed orientation in space. To meet the stringent accuracy requirements of inertial-guidance systems for space rockets, the stabilized platform must maintain its angular position within a fraction of a degree, for several hours.

2. Any mass permitted to make constrained movements is subject to friction. In our spring-mass accelerometer, for instance, the inert mass is constrained by springs, whose stretching or squeezing involves some friction. (Just bend a piece of wire a few times, rapidly, and feel the heat produced by the friction!) Also, unless the accelerometer operates in a vacuum, there will be air friction. The potentiometer pickoff is another source of friction.

All this friction reduces the accuracy of the whole system. It is no overstatement to say that the success of modern inertial-guidance systems is the direct result of a relentless fight against friction. Many methods have been tested in this fight:

There are "flotation bearings" where the suspended mass floats in a fluid of equal density. There are "gas bearings" in which the suspended mass rides upon a cushion of air or nitrogen. There are electrostatic supports, and even magnetic supports, which utilize the strange effects of electrical superconductivity at extremely low temperatures.

Accuracy of the system is improved, too, by increasing the forces created by acceleration. Gyro accelerometers, utilizing the phenomenon of gyroscopic "precession," have proved superior to simple mass-spring accelerometers.

Further gains in accuracy have come

CONTINUED

from performing integration operations, not with friction-plagued electric motors, but with friction-free electronic digital computers.

Present-day inertial-guidance systems can place a satellite in orbit with an injection accuracy of a few feet per second in velocity, and a fraction of a mile in altitude.

Q ***What is a solar battery?***

A It is a source of electrical power for spacecraft. A solar battery is made up of a bank of solar cells. These are small shingles of pure silicon, whose outer surfaces have been contaminated by exposure to boron vapor. Sunlight striking these cells is converted directly into current. Here is how this works:

The smallest unit to which electricity can be reduced is the *electron*. Similarly, light energy cannot be subdivided beyond a unit called a *photon*.

A light photon impinging on the boron-contaminated surface of a silicon shingle is absorbed within a layer not exceeding 1/100,000 of an inch in depth. Its absorption invariably leads to the displacement of an electron. While free electrons are few and far between within the boron-containing layer, they are in ample supply in the pure silicon beneath. As a result, when enough energy has been imparted to a displaced electron to propel it from the boron-doped layer into the pure-silicon region, it is free to move into an external circuit where it helps to deliver power.

Solar batteries produce only a few watts of electrical power per square foot of panel surface. In order to drive high-powered transmitters for deep-space communication, they usually feed their weak but round-the-clock power into a chemical storage battery capable of high-power, short-time discharge. ■ ■

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We Test Those HOT COMPACTS

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WERNHER VON BRAUN on Observatories in Space

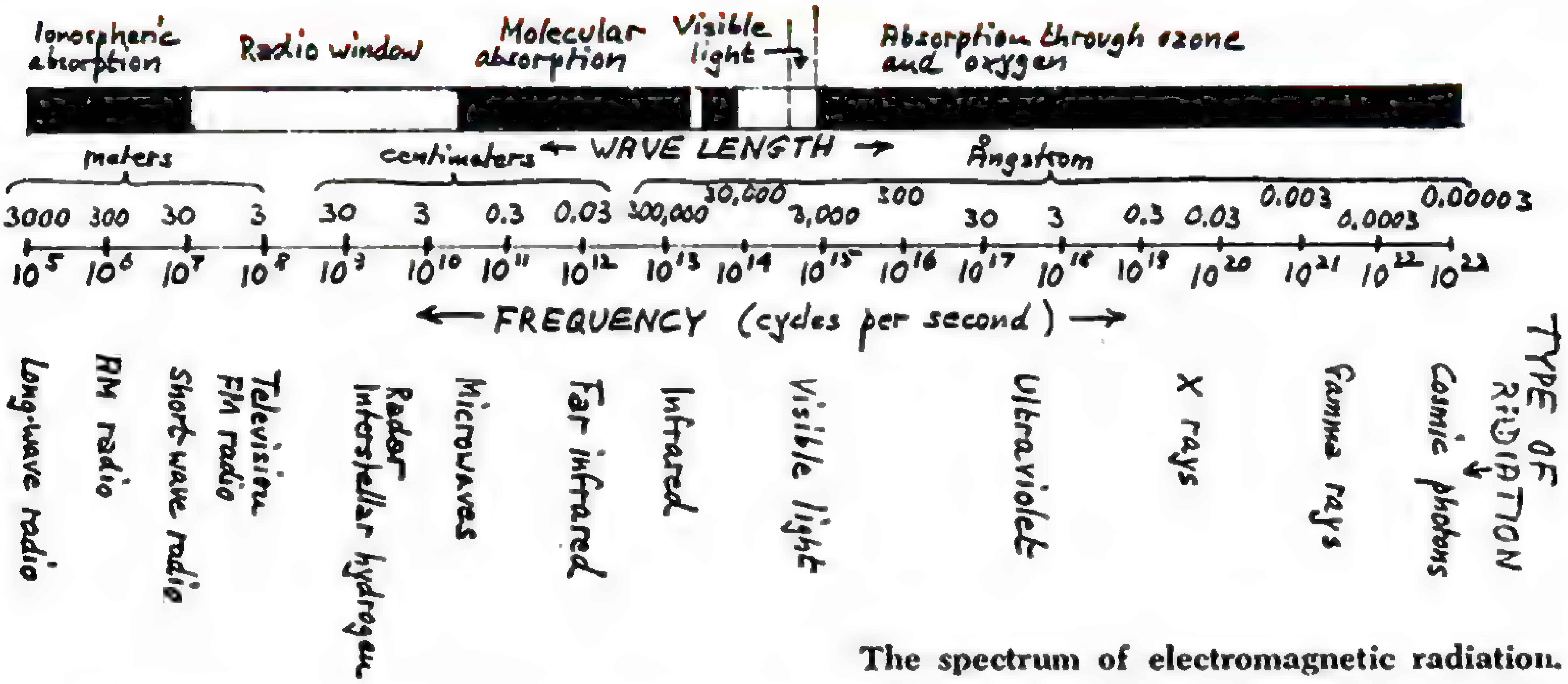
Now You Can Have Hi-Fi TV Pictures

Why Sports Records Are Toppling

Dr. von Braun (right) confers with Harrison Storms Jr., chief of Apollo project at North American Aviation.

Dr. Wernher von Braun Answers Your Questions About

Observatories in Space



The spectrum of electromagnetic radiation.

Q ***Why are space vehicles used to study extraterrestrial radiation?***

A Radiation from stars, nebulae, and distant galaxies provides the only clue to understanding them.

Outer space is pervaded by their entire spectrum of electromagnetic radiation, shown in my diagram. It ranges in wave length all the way from 0.00003 Angstrom (an Angstrom is one ten-billionth of a meter) up to 3,000 meters. The corresponding frequencies also are shown in the diagram.

But we live at the bottom of a dense atmosphere that absorbs most of this radiation, and so is opaque to it. Only a small portion penetrates to the earth's surface. In essence, our atmospheric shell provides only two "windows": one for visible light (with wave lengths of 4,000 to 8,000 Angstroms) and a bit of the infrared, and the other for radio waves (between about one centimeter and 30 meters in wave length).

For centuries, astronomical observations of celestial objects were limited to the narrow window admitting visible light. In recent years, radio telescopes have opened the "radio window" and gleaned much new information.

Space vehicles, operating outside the earth's atmosphere, can observe the *entire* spectrum of electromagnetic radiation. Manned or unmanned, they offer an ideal platform for studying the universe, with radiation-sensitive instruments that cannot be used on earth. Even a casual glance at the little diagram shows that these new observational

CONTINUED

tools are bound to multiply our knowledge of the universe.

Q ***What practical use can we foresee for such studies?***

A We expect plenty.

Nothing is more difficult to predict than the profitable applications of a new discovery. But in the last analysis, all the things that fill our everyday needs—the food we eat, the clothes we wear, the automobiles we drive—are the result of someone's desire to explore the unknown. The harnessing of nuclear power, whether in the atom bomb or in a power-generating reactor, can be traced back directly to astrophysical studies—of the sun, in particular.

We should always bear in mind that all plant and animal life on earth would be extinct within a few hours if the sun suddenly ceased to shine.

A better understanding of the mechanism of energy transfer from the sun to the earth will undoubtedly lead to a better understanding of everyday problems down here on earth.

Q ***What are we trying to learn from solar radiation?***

A The sun is our most powerful source of stellar radiation. We can consider it the nearest fixed star. Because of the window problem, we still know very little about solar ultraviolet and X-ray radiation. But what little we have learned so far from artificial satellites clearly indicates that some of the previous ideas held by astrophysicists—particularly about the intensity of ultraviolet emissions of hot stars—have been woefully wrong.

We are still completely in the dark about the causes of the sun's mysterious 11-year sunspot cycle. Scientists have known for years that there is a close correlation between this sunspot cycle and the earth's magnetic variations and polar lights. The discovery of the Van Allen belt has provided some clues for the mechanism of this interaction. But we simply do not know what causes the sun to "breathe" in that cycle.

Conceivably, part of the heat energy continuously released by the huge nuclear reactor operating in the sun's interior, instead of flowing evenly outward to the surface, may be dammed up in some fashion so that it comes through in rather gentle periodic surges.

Variable stars with great changes in brightness are quite common in the universe—and it is fortunate indeed that our own sun's cyclic variations are so small that 100 years ago it was not even known they existed. They went undetected for so long primarily because the sunspot cycle is not accompanied by any noticeable variation in visual brightness—in other words, as observed by visible light.

It can be expected that in the hitherto inaccessible ultraviolet region, very noticeable fluctuations will be recorded. NASA's orbiting solar observatories will be equipped to record such radiation data. But for results we must be a bit patient. We'll have to wait for the length of at least one 11-year cycle.

Q ***Is there any connection between the sunspot cycle and the weather?***

A Yes. Meteorologists have learned, to their dismay, that the statistical accuracy of their predictions is adversely affected by increased ultraviolet radiation from the sun.

The reason for this is easy to understand: The art of weather forecasting is based upon the principle of causality. In other words, the U. S. weather map for Tuesday is a direct logical deduction from the trends depicted on the weather map for Monday. But such cause-and-effect reasoning is permissible only as long as one analyzes a "closed system," such as an atmosphere subjected solely to internal disturbances, while exposed to a steady, unvarying influx of solar radiation. As soon as the situation is altered by external factors—such as unrecognized changes in solar ultraviolet radiation—the beautiful causal

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reasoning falls apart, and the results of weather predictions become disappointing.

Today there is no operational, round-the-clock, satellite-borne recording system for solar ultraviolet radiation. But within a few years we shall have it. Along with making a continuous survey of the atmosphere's ozone layer (which goes up to 60-mile altitude and can be reached with simple rocket probes), it will enable meteorologists to pin down exactly those external influences on our weather. Tiros and Nimbus-type satellites with their TV cameras will keep a watchful eye on the earth's ever-changing cloud patterns, too.

Once all these new sources of knowledge are tied in with the existing weather stations, by a rapid-fire global communications system, we can rightfully expect weather forecasting to reach new heights of accuracy.

Q ***What is cosmic radiation?***

A The term cosmic radiation, or cosmic rays, is used for elementary particles that crisscross outer space at velocities approaching the speed of light.

The majority of these particles are protons, the nuclei of atoms of hydrogen (atomic weight, 1). But heavier nuclei up to those of indium (atomic weight, 114.8) have been detected. By and large, the particle count diminishes with increasing particle weight, but some heavier elements such as iron (atomic weight, 55.8) are relatively abundant. Although evidence is still a bit sketchy, some scientists believe that the atomic-weight distribution of cosmic rays reflects the relative abundance of the chemical elements throughout the universe.

This has led to the theory that cosmic rays might be the debris of tremendous thermonuclear explosions of stars. Such exploding stars have been observed by astronomers and are called *supernovae*.

However, some cosmic-ray particles travel so fast that even a supernova explosion could not account for their en-

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ergy. It is believed such high-energy particles derive their extra speed from being bounced back and forth, between the magnetic fields that accompany vast, moving interstellar clouds of extremely tenuous ionized gas or *plasma*.

Cosmic radiation of a lesser energy level is known to come from the sun, particularly during solar flares. Such lower-energy particles approaching the earth are deflected, by the earth's magnetic field, toward the North and South Poles. Thus, total cosmic-ray intensity is at a minimum over the earth's equator.

Cosmic-ray particles as encountered in outer space are often called *primaries*, to distinguish them from the cascade of secondary particles generated by their collision with air nuclei in the upper layers of our atmospheric shell. These secondary particles shower down through the atmosphere. Although their intensity tapers off with decreasing altitude, they can be detected at the ground and even several hundred feet under water.

The question of the physiological hazards of cosmic radiation to astronauts is still hotly debated. Surprisingly, radiologists are not concerned about the most energetic primary particles. These go through the human body so fast that they have no time to do damage.

The greatest potential hazard is posed by a slow, heavy primary that comes to a "screeching halt" in the human body. In this case the positively charged primary particle has time enough to jerk a whole string of electrons out of the atomic shells of the body tissue, along the path of its "terminal retardation," or final braking. Some radiologists believe that certain areas of the human body, such as the brain and spinal cord, might be endangered by extensive exposure to such "slow-down hits." Hence they are advocating extra radiation protection for longer space flights. ■ ■

Dr. von Braun will consider answering questions from readers of Popular Science in the magazine, but he cannot undertake to answer each one by mail. Letters to him should be addressed in care of Popular Science, 355 Lexington Ave., New York 17, N. Y.

JUNE 1963 35 CENTS

Popular Science Monthly

WERNHER VON BRAUN: Putting a Spacecraft "in the Groove"

If Your Car Goes in the Water

Findings by Michigan State Police and Indiana University That May Save Your Life

New Stereo Tape Changer

Test-Driving the 1896 Ford

World's Hottest Handgun

Beefed-Up Cars—Built for Towing

Rocket experts compare notes —Dr. von Braun, left, and Krafft Ehricke of General Dynamics/Astronautics.

Dr. Wernher von Braun Answers Your Questions About Guiding Spacecraft to Other Worlds

Q ***How is a spacecraft guided to the moon or a distant planet?***

A On the way, its aim is refined by a mid-course correction maneuver. This is a powered maneuver to correct any inaccuracies of its "injection" into its trajectory—the start it has been given by its launch rocket.

The term "mid-course" does not necessarily mean that this maneuver will be conducted at the halfway point to a celestial target. For propellant economy, it is advantageous to perform the mid-course correction maneuver well ahead of the midway point—in fact, the sooner the better. However, to give the corrected flight path the highest possible accuracy, it is necessary to wait long enough to track precisely and nail down the original uncorrected trajectory.

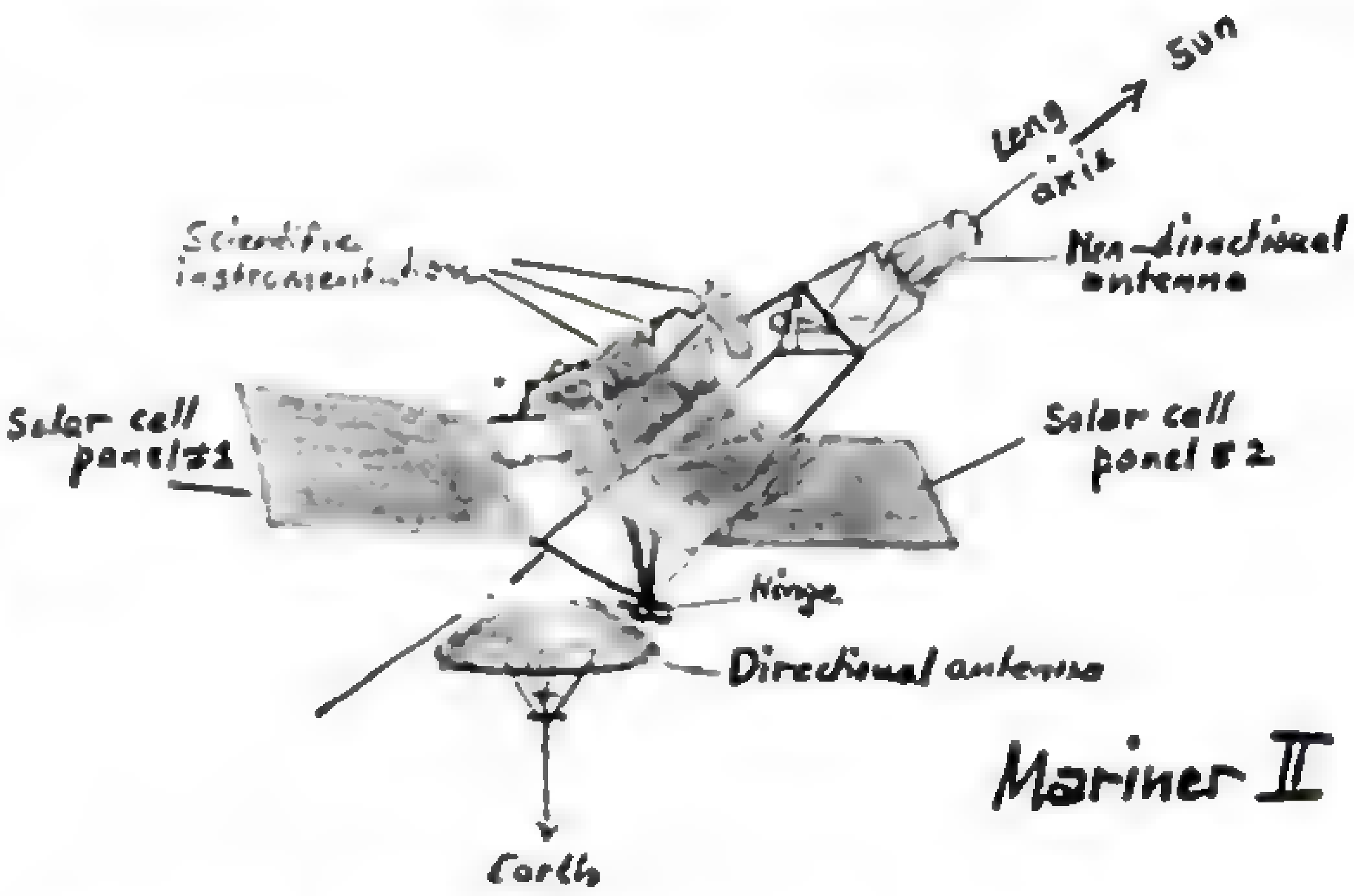
There may be just one mid-course correction maneuver—or several successive ones. One correction usually will suffice if accuracy requirements for the spacecraft's approach to its target are not too stringent. Missions involving extreme precision, such as orbital capture by the moon or a planet, are likely to require two or more corrections.

Q ***How is the maneuver executed?***

A NASA's spectacularly successful Mariner II Venus probe provides a fine example:

Mariner II, a product of NASA's famed Jet Propulsion Laboratory, was launched on Aug. 27, 1962, from Cape Canaveral. A converted Atlas D intercontinental rocket was the launch vehicle, and an Agena B served as second stage.

The Agena's rocket engine was shut down after Mariner II's successful injection into a parking orbit, 115 miles up. After a 13-minute coast along this orbit, the engine was restarted. It kept firing until the Agena B, with the 447-pound Mariner II spacecraft still strapped to



its nose, was injected into an escape trajectory toward Venus at 25,700 m.p.h. This occurred approximately over Ascension Island in the South Atlantic Ocean, about 25 minutes after launch.

About two minutes later, Mariner II was separated from the burned-out Agena; its aerodynamic shroud had already been jettisoned at Atlas burnout, five minutes after lift-off.

About an hour after launch, Mariner II was instructed, by radio command from the ground, to "acquire the sun." The spacecraft was equipped with six sun sensors (light-sensitive diodes) that

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provided a complete field of view, covering all directions. The sun, by far the sky's brightest object, could be mistaken for nothing else. The sensors, wired to the valves of a nitrogen-jet attitude-control system, turned the spacecraft until its long axis pointed at the sun.

Mariner II's butterfly panels with their 9,000 solar cells, unfolded by a previous radio command, were thus swung into position to be bathed in continuous sunlight. No longer did instruments depend on feeble chemical batteries.

One week after launch, Mariner II was instructed to aim its directional dish antenna toward the earth. During this "earth acquisition," the spacecraft maintained its lock on the sun. But it rolled on its long axis (pointed at the sun) in response to a short blast from the gas nozzles—and, with its dish antenna tilted at a preset angle, started "looking" for the earth.

Successful acquisition of the earth by the large directional antenna manifested itself by a sharp rise in signal strength. (Up to that moment, all communications had been through a separate, non-directional spacecraft antenna.) In this position, a small counterblast of the gas nozzles stopped the spacecraft's roll.

Mariner II now coasted along its unpowered trajectory toward Venus, sta-

About the drawings

In answer to readers who have asked, the illustrations accompanying these questions and answers are by Dr. von Braun himself.

When he began this column in PS, it was expected that drawings for it would be put in professionally finished form by a staff artist, using rough pencil sketches from Dr. von Braun for guidance.

As it turned out, the editors found Dr. von Braun's own informal sketches not only crystal clear in themselves, but as personal, direct, and authentic as if the famous scientist were chalking them on a blackboard before our eyes. Believing that you will find them so, too, we are illustrating his answers to space questions with direct reproductions of his original penciled drawings.

CONTINUED

bilized on two axes—its long axis pointing at the sun, its directional antenna at the earth. In this attitude it began its mid-course correction maneuver—which was carried out, eight days after launch, on Sept. 4, 1962.

Up to this time, tracking data collected by three 85-foot radars—spaced far apart in California, South Africa, and Australia, for continuous coverage from the rotating earth—had been fed into an electronic computer [See "Ranger 6, Where Are You?" p. 64]. The computer compared the actual trajectory of Mariner II with the trajectory required to pass Venus at a distance of about 10,000 miles. Thus it provided data for correcting the actual trajectory, to offset its deviations from the desired one.

These data now were radioed to the spacecraft, in three distinct commands:

1. Roll through a certain angle about the spacecraft-sun axis.

2. Pitch up through a certain angle. (That is, turn the outer end of one of the two butterfly panels a bit more toward the sun, and the opposite panel's outer end away from the sun.)

3. Fire a little 50-pound-thrust motor until a certain velocity has been added in the direction of Mariner II's long axis. (The rocket motor could contribute up to 200 feet per second.)

With these three commands properly executed, Mariner II was "in the groove." To get its temperature control and communications system back in good shape, the spacecraft reacquired sun and earth. It remained in this attitude during the rest of its journey and its approach to Venus, when it activated its data-gathering instruments.

After a 180-million-mile flight, Mariner II passed Venus on Dec. 14, 1962, at a distance of 21,000 miles. It radioed back invaluable and unprecedented data, and lifted the first veils from the mysteries of this intriguing planet.

Q ***What are "ullage rockets"?***

A They are a set of small rockets that assist in the start-up of liquid-propelled

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upper stages of large-size rocket ships.

After shutdown of the first-stage engines, and prior to ignition of the second-stage engines, a multistage rocket ship coasts unpowered through the vacuum of outer space for a few seconds. Since its tanks and the liquid propellants in them follow the same unpowered trajectory, there is no differential force of any kind to hold the now-weightless fluids in place within the tanks.

As a result, the danger exists that the second-stage propellants may cling to the tanks' walls and the upper tank bulkheads, unporting the outlets to the rocket engines. When the pumps are started to feed the propellants into the second-stage engines, their intakes may, instead, suck in tank-pressurizing gas out of the ullage. (The term "ullage" denotes the gas pocket above liquid in a container.)

Ullage rockets serve to prevent this from happening. Their accelerating force keeps the propellants settled on the respective tank bottoms—and the ullage on top of the liquid where it belongs. These rockets fire for a few seconds only. They are ignited just prior to thrust termination of the lower stage, and stop firing after the upper stage's own thrust has been fully established.

It is customary to attach ullage rockets to the outer skin of the large rocket. Second-stage ullage rockets, having a one-shot task, usually consist of a set of two or four small solid-fuel rockets, which are sometimes jettisoned after use.

Ullage rockets for third stages, or for spacecraft-propulsion systems requiring several restarts, are often liquid propelled and combined with the attitude-control jet system. To prevent unporting of the rockets' own propellant outlets, so-called "positive displacement bags" separate the liquid propellants from the gas ullage. ■■

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Monthly

What Will the '64 Cars Be Like?

"Camping Out" at 100 Fathoms

How Ed Link's Divers Live Beneath the Sea

How to keep cool

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Exciting $3.95 Book Digest

When Uncle Sam Played Dirty—
DEADLY GADGETS OF THE OSS

Will we ever go beyond the planets?
Wernher von Braun talks about travel to the stars

Dr. von Braun (right) with J. R. Dempsey, president of General Dynamics/Astronautics.

Dr. Wernher von Braun lays the cards on the table

Can We Ever Go to the Stars?

Will we ever be able to travel to solar systems beyond our own?

The past 20 years should have taught us to use the word "impossible" with utmost caution. Nevertheless, human travel beyond our own solar system is a staggering concept. Even the most reckless optimists do not expect it to come about in our generation—or the next.

Light, traveling at 186,000 miles per second, needs 8.3 minutes to span the 93 million miles between the sun and earth. Light takes 5½ hours to travel from the sun to Pluto, outermost planet of our solar system. But it takes 4.3 years to reach Alpha Centauri, the nearest fixed star (4.3 light-years away); 470 years to Polaris; and 27,000 years to get to the center of our galaxy—a lens-shaped island in space, a little less than 100,000 light-years in diameter, made up of an estimated total of some 200 billion suns.

Can we build a rocket powerful enough to travel so far?

We have to impart to an object a velocity of slightly more than 25,000 feet per second to place it in a low orbit around the earth. About 36,000 feet per second is needed to hurl it to the moon—which is still within range of the earth's pull—and just a trifle more to kick it completely out of the earth's gravitational field. If we accelerate it up to a terminal speed of 56,000 feet per second (in such a fashion that it leaves the earth in the same direction in which the earth is orbiting at 107,000 feet per second around the sun), it will enter a parabolic flight path and escape from our solar system.

From the point of view of power re-

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Phew . . . and now, back to something easy like designing rockets!

…ticle and … them last week … ded
them to get the information out to you right away.

Sincerely yours,

x) I'm really proud of it.
It's a stinker, to make
"relativistic" concepts
simple!

Wernher von Braun

Wernher von Braun

Encl
a/s

It's no small feat to make understandable the eerie problems of "relativistic" space flight to stars thousands of light-years away. So PS echoes this impromptu postscript that Dr. von Braun jotted on his letter forwarding this month's manuscript to Editor Bob Crossley.

quirements, a needed velocity of 56,000 feet per second (38,000 m.p.h.) may not sound too bad. Just one extra stage on top of the Saturn V, our Apollo moon rocket, could impart that speed to an object of about 8,000 pounds. But as the object coasted, its power spent, on its "uphill" path out of the pull of the sun's gravity, its speed would gradually diminish almost to zero. Millions of years would elapse before it reached one of the nearest fixed stars.

To reduce travel time to figures compatible with the life span of man, travel speeds must approach the speed of light.

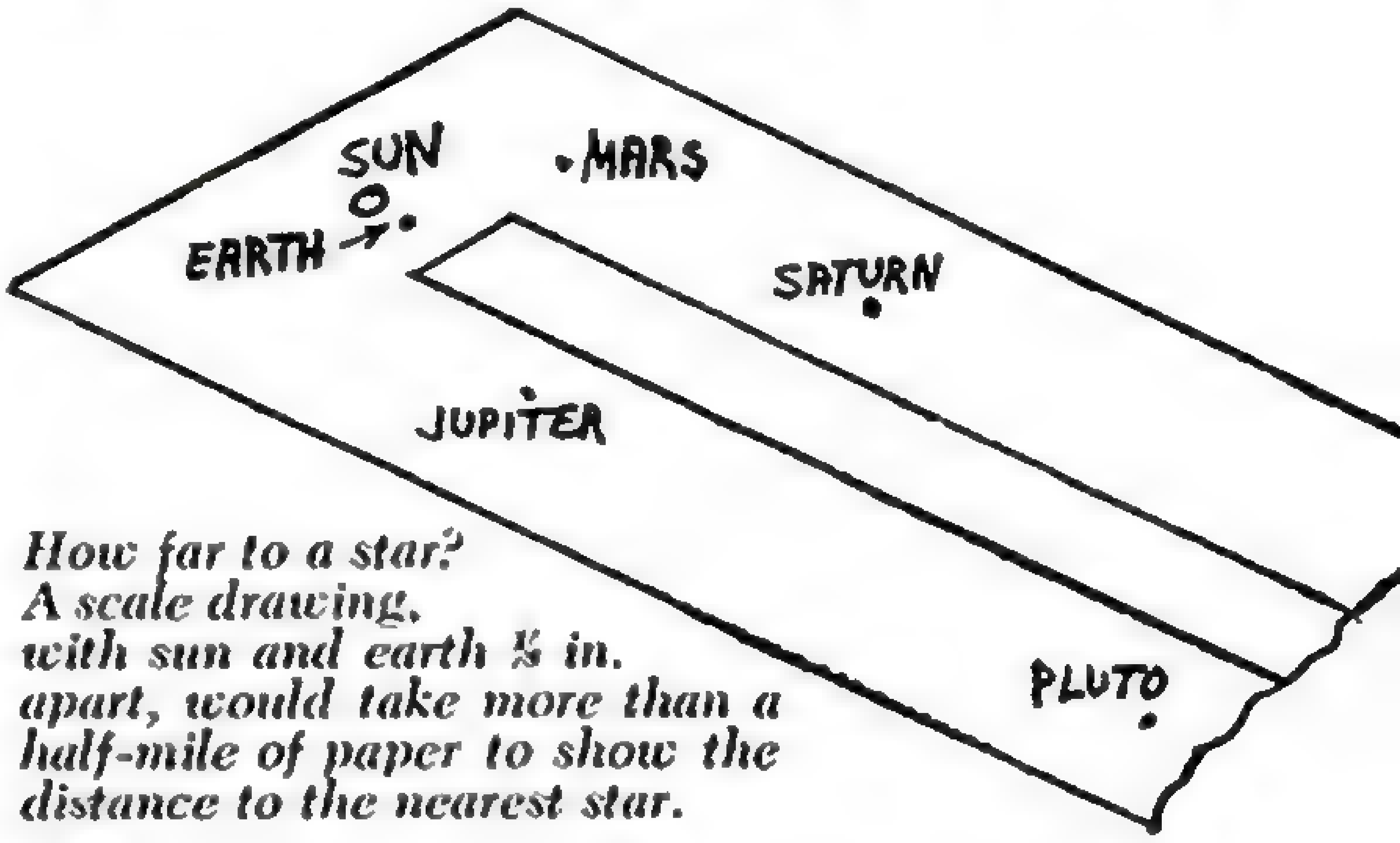
Not even nuclear-fission or nuclear-fusion processes are adequate to produce such speeds. For all their dramatic display of power, they convert only a tiny fraction of the mass involved into energy. It would be necessary to devise a rocket mechanism wherein the *entire* mass, M, of the injected "propellant" is converted into radiation energy, E, according to Einstein's famous equation: $E = M \times C^2$. The exhaust of such a "photon rocket" would be a beam of radiation, and the exhaust velocity would of course be equal to the velocity of light, C.

The problem is that nobody knows how to build a photon rocket. Certain subatomic processes are known, such as the joining of an electron (a small negatively charged particle) with a positron (an equally small positively charged particle), that directly transform matter into energy according to Einstein's equation. But so far, physicists have been unable to devise any large-scale processes for this transformation.

There are also tremendous engineering obstacles. By definition, a photon rocket converts its propellant stream into an extremely powerful light beam. To bundle this beam, some sort of mirror is needed. Even if it had a reflectivity of 99 percent, better than our best existing ones, that one percent of absorbed radiation energy would instantly melt the mirror—considering the billions of kilowatts converted into the power carried away by the light beam.

Q ***Is it true that it is impossible to exceed the speed of light?***

A Yes. But as we shall see, this is partly a matter of definition. Suppose we had overcome the "minor" problems just described, and we did have a rocket capable of "beaming away" 100 percent



How far to a star? A scale drawing, with sun and earth ⅛ in. apart, would take more than a half-mile of paper to show the distance to the nearest star.

of the mass of its propellant with an exhaust velocity equal to the speed of light. What could we do with it?

If the rocket had a mass ratio (the ratio between its fully fueled and empty weight) of 3, it could reach 80 percent of the speed of light. With a mass ratio of 10, its terminal velocity would be about 98 percent; and with a mass ratio of 1,000 (about what we have today in some of our chemical multistage planetary rockets), we would hit 99.9998 percent of the speed of light.

Again we refer to Dr. Einstein. His Theory of Relativity (which has stood the test of many critical experiments, and has been universally accepted by the scientific community) shows that *the inertia of an object's mass approaches infinity as the object approaches the speed of light.* Hence it would take infinite power to accelerate an object beyond the "light barrier."

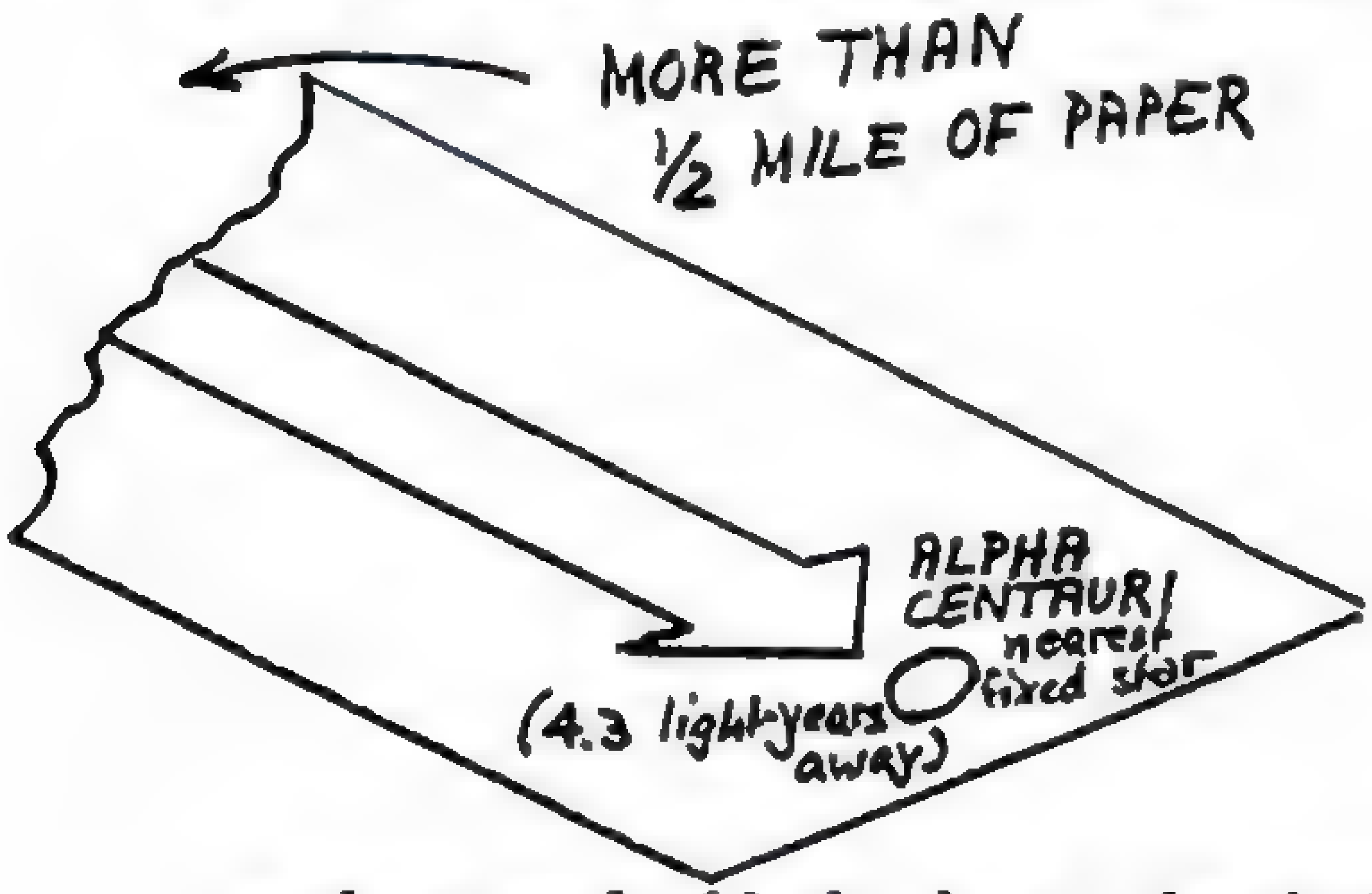
But, amazingly enough, the same theory states that a stellar astronaut could still travel to a star 1,000 light-years away and return within his adult life.

Q *How could an astronaut travel 2,000 light-years in a lifetime?*

A "Time dilation" would help him to stay young. For many people, the strange phenomenon called time dilation is a hard pill to swallow. The flow of time appears to us completely unaffected by physical conditions. Whether we sleep or work, sit at a desk or in a speeding jetliner, our wrist watch seems to tick away at the same pace. So does our heart.

But the fact is that this cherished piece of "everyday experience" is valid only in the realm of relatively low velocities in which we slowpokes live.

A meson (an unstable subatomic particle), when traveling at a velocity close



to the speed of light, has a clearly longer decay time than its 2.1-microsecond "half-life" at lower speeds—when an earth-fixed observer does the timing. But if the observer were flying along with the meson, the half-life of 2.1 microseconds would not seem to be affected by the particle's speed, since the observer's watch would be subjected to the same time dilation as the meson itself.

The Theory of Relativity tells us that the pace of time becomes slower and slower for an object approaching the speed of light, compared with time's rate of passage for a stationary observer. At the speed of light itself—an upper limit that no object can ever reach—time would come to a complete standstill. If an object could go so fast, it could cover vast distances while, for a man flying along with it, no time would elapse—neither for his watch nor for his heartbeat, which controls his life span.

This strange effect makes it possible for a stellar astronaut to travel from the earth to a fixed star 1,000 light-years away, in what he would think was 13.2 years. For the trip back he would need another 13.2 years. If he didn't spend any additional time at his destination, he would thus have been away from the earth for 26.4 years. The trouble is that, during his absence, more than 2,000 years would have elapsed on earth. Thus, upon return, he might wind up in a zoo.

Q *What would a trip to a star be like?*

A Let us assume we have a photon rocket capable of a continuous acceleration of 1 G. Suppose, too, that our mass ratio is large enough to get us very close to the speed of light; carry us to a star 1,000 light-years away; and slow us down again to normal speeds, so we can visit one of the star's planets. The rocket is also to be capable of flying us back to earth—possibly by "refueling" during the stay at that distant solar system.

As we depart from the earth, the stars of the firmament will first appear in their familiar yellowish hue. As our vehicle builds up speed toward our target star, the Doppler effect will cause a striking change in this star's color. From its original yellow, the light received from it will shift through green, blue, and violet, and toward ultraviolet—in other words, to higher frequencies. Simultaneously the color of the receding sun will slowly change from yellow to orange, red, and toward infrared—that is, to lower frequencies.

This is easy to understand: A boat running *against* the waves is hit by them at a *higher* frequency than a stationary pier is; a boat running *with* the waves, at a *reduced* frequency.

After about 3½ months our stellar photon rocket has reached about 30 percent

[*Continued on page 170*]

[Continued from page 65]

of the speed of light. The frequency of the sun's peak radiation output now passes the border of the visible spectrum and moves into the infrared. As a result, the sun dims rapidly, and soon becomes invisible. One month later, the destination star likewise becomes invisible—the peak of its radiation intensity has shifted into the ultraviolet.

As our velocity keeps increasing, two circular dark spots are formed around the destination star and the sun, and keep growing in diameter. Between these blind "bow and stern spots," the stars of the firmament appear as a multicolored array of concentric circles, like a huge rainbow:

Near the black bow spot, the stars look violet. Further aft, they are blue and green. Abeam, they shine in their original yellowish hue. Still farther aft, they look orange, and the dark stern spot is surrounded by a ring of red stars.

Due to "relativistic" effects, the dark bow spot grows only to an opening angle of 43 degrees. After we exceed 74 percent of the speed of light (11 months after departure), it begins to contract again. But the stern spot around the sun continues to grow steadily. Hence, as our traveling speed approaches the speed of light, the visible portion of the firmament will become compressed into an ever-narrowing rainbow around the invisible target star.

The opening angle of the yellow ring, in this rainbow, is a perfect yardstick for the ratio between our traveling speed and the speed of light. In analogy to the well-known Mach Number (ratio of flight speed to speed of sound), this ratio is sometimes called the Einstein Number.

In 6.6 years from the time of departure, our speeding photon rocket hits Einstein Number .999998, and we are at the halfway point of our journey. However, on trying to measure the remaining distance to our destination star (now emitting predominantly X rays), we find it only about a light-year away! In fact, without further power application, we would pass it a year later—7.6 years' "dilated ship's time" after departure—if we were to refrain from slowing down for our forthcoming visit.

But in order to visit one of the star's planets, we have to turn our ship around and use our photonic rocket thrust for braking. Of course our slowing down means that we'll reach our target, not in another year, but much later. Only after another 6.6 years—13.2 years after departure—will we near our target, at a relative approach speed close to zero. During the second 6.6 years—that is, during the retardation maneuver—all those celestial "rainbow" phenomena of the acceleration period will take place in reverse. Upon arrival, the firmament will look like its old self again.

If we had a telescope powerful enough to observe events on earth from our new vantage point, we would find our home planet very much as it was when we left it. But, being 1,000 light-years away, we are actually watching events that happened on earth 1,000 years ago. (This is the non-dilated time that has elapsed *on earth* since we left.) The amazing thing is that, due to the time dilation aboard our speeding rocket, we have aged only 13.2 years during our outbound voyage.

Eerie as this may sound, it is all in perfect harmony with modern ideas of the laws of space and time. (Men today have the same difficulty in accepting the concept of relativistic time that our ancestors had in seeing how people "down under" in Australia could walk head down without dropping off the globe. But that is because our experience does not include very great distances and extremely high speeds.)

While the insights of modern physics permit us to dissect the anatomy of interstellar flight, we must forego rash conclusions that any such flights are imminent, or feasible. We cannot yet even define an adequate power source. If we had it, many problems of using it would be beyond us. Other obstacles may be even more formidable. For instance, what would happen to an interstellar rocket that hit even a small meteoroid, if the collision were at nearly the speed of light?

In summary, with our present knowledge, we can respond to the challenge of stellar space flight solely with intellectual concepts and purely hypothetical analysis. Hardware solutions are still entirely beyond our reach and far, far away.

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AUGUST 1963 35 CENTS

Popular Science Monthly

HOW TO GET STARTED IN **Scuba Diving**

WERNHER VON BRAUN ON **Mars**

The Fine Art of *Fast Driving*

PLUS What's Your Car Worth?

Now—the first time in any magazine—latest used-car values prepared exclusively for Popular Science by the auto Red Book. Chevrolet, Dodge, Mercury, Olds, Rambler and others.

Dr. von Braun, left, addresses national space conference in Chicago. With him is David M. Kennedy, chairman, Committee for Economic and Cultural Development of Chicago.

Dr. Wernher von Braun takes a look at MARS

Are its canals full of water? Is there really life there?

Timetable to planet Mars

Solving Mars' mysteries with space probes—as foreseen here by Dr. von Braun—could come as soon as this year or next.

The first U.S. attempt is planned for the next favorable launch date, which will come about November, 1964. After that, the best time would be about December, 1966.

A Soviet Mars probe was launched at the last favorable date, in late 1962, but failed in its mission—radio contact was lost before it passed Mars last June. Now the Russians announce they'll try again in 1963. If they do, instead of awaiting a favorable date to conserve power and permit maximum payload, the launch will be an innovation in planetary shots.—The Editors.

Q ***What are the canals of Mars?***

A When Mars was in a particularly favorable position for observation in 1877, the Italian astronomer Giovanni Schiaparelli announced the discovery of a network of very narrow and perfectly straight lines, which seemed to crisscross the surface of Mars like a spider web. For want of a better word he called these lines "canali."

As other astronomers got into the act to verify (or refute) Schiaparelli's canals, a whole set of criteria for these mysterious lines emerged in the professional literature:

- Most canals, observers reported, followed great circles of the planet's sphere.
- First observed only in the bright ("desert") regions of Mars, the canals were found to cross some dark areas, too.
- In areas covered overnight by "snow" (now believed to be hoarfrost), a canal was still clearly discernible, although its width was greatly reduced.
- All canals began and ended in dark regions, or in dark spots called "oases"; none was ever seen to disappear in a bright "desert" region.
- The canals' visibility was clearly linked to the seasons on Mars. As the white northern polar cap receded during the Martian spring, canals of the northern hemisphere

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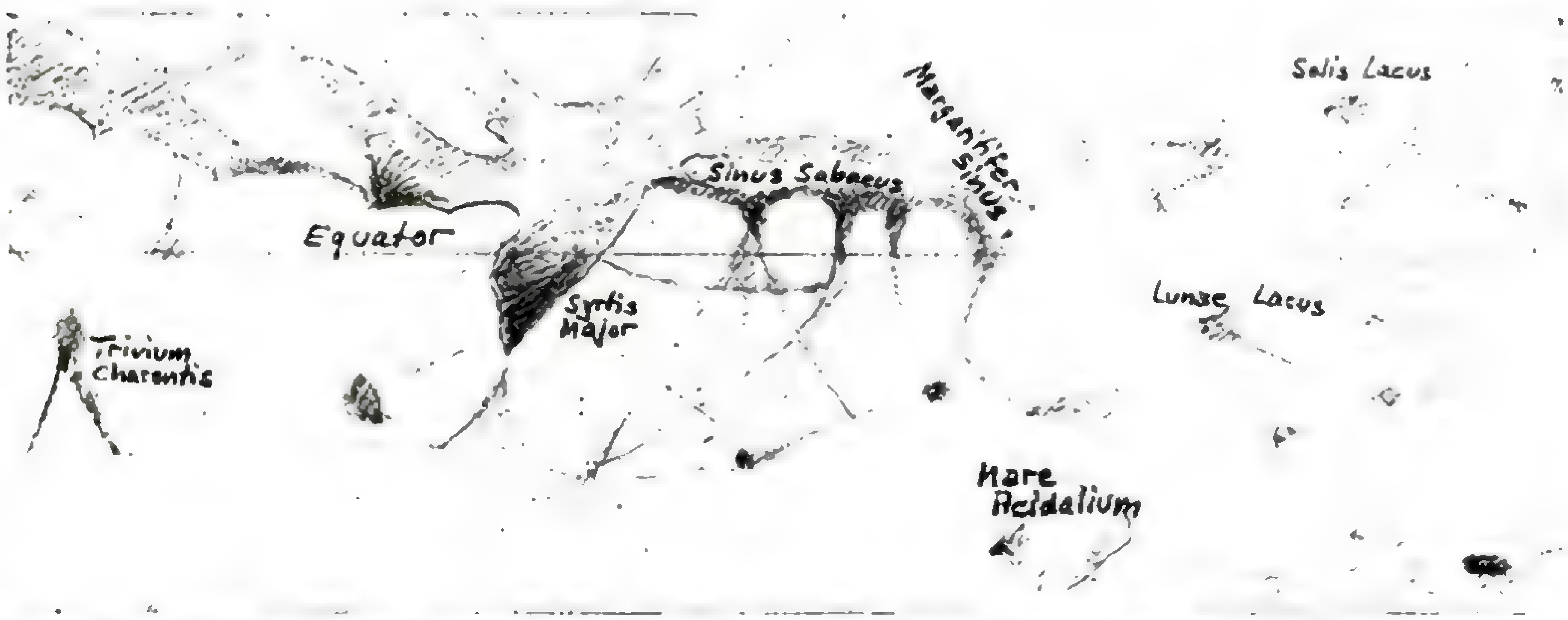

Sketch by Dr. von Braun shows Mars' canals and dark areas, with Latin names of major features.

increased in strength and contrast. Half a Martian year later, the same phenomenon took place in the southern hemisphere.

- During periods of seasonal strength, a strong canal would suddenly appear doubled. Where there had been a single great-circle line the night before, there would now be two parallel lines.

Did Martians dig the canals?

All these exciting observations inevitably led to speculation that the Martian canals might be the handiwork of highly intelligent beings. The flagbearer of this proposal was the American astronomer Percival Lowell, one of the most outstanding planetary observers of all times. Mars was a dry planet, his reasoning went—well over half its surface was arid desert. Its main supply of water was available when its supposedly snow-covered polar caps melted during northern or southern springtime.

What would be more logical, therefore, than for Martians to develop a system of irrigation canals—to carry water from the melting polar snow caps to warmer latitudes, where food crops could be grown only if the ground were watered? To Lowell and his school, what they saw of a canal was not the water-carrying ditch itself—it would have had to be hundreds of miles wide to be seen with telescopes available then—but the bands of vegetation on both sides, like the green banks along the Nile or Rio Grande. Lowell's intriguing idea found worldwide support.

But, with the advent of more-advanced telescopes, it was finally shot to pieces. Using these more-powerful instruments, observers could clearly see much fine detail that had eluded the smaller telescopes of Schiaparelli and Lowell. Now a canal, instead of being a straight thin line, took on the appearance of a succession of irregular details.

Moreover, our present knowledge of Martian atmospheric pressure and surface temperatures precludes the possibility of open water.

We now know with a high degree of certainty that the small amount of water available on Mars is carried through the atmosphere in the form of ice crystals. Winds deposit this ice as hoarfrost in the

CONTINUED

Dr. Wernher von Braun continued

polar regions during the winter months of the respective hemispheres. At winter's end the hoarfrost layer forming a polar cap has an estimated thickness of only a fraction of an inch.

However, the most up-to-date observations fully confirm the existence of predominant directions along which "activities" on the face of Mars are oriented. A canal is now looked upon as an axis along which is clustered a great deal of detail. Seasonal variations of the contrast with which this detail may be observed have likewise been fully verified.

Further, after many decades of carefully recorded observations of Mars, it has become quite evident that some previously reported areas of conspicuous detail and contrast have now become quite faint. Conversely, some formerly faint areas have become much stronger. And some areas, such as the Nepenthes-Thoth region, alternate between phases of great intensity and faintness.

Summing up, we can only say that the canals of Mars remain a riddle. Unlike the moon, which is a dead world, the surface of Mars shows seasonal as well as long-term changes. It is an immense challenge for future astronauts.

Q ***Can we expect to find life on Mars?***

A Astronomers are extremely reluctant to answer this question with a flat "yes" or "no." The available evidence really is still too tenuous. In the past, researchers were often carried away by their enthusiasm and strong convictions. Now, in this age of planetary rocket probes, they are painfully aware that they can no longer make pronouncements—which may be refuted tomorrow by overwhelming new evidence—with impunity.

The question of life on Mars centers about the planet's dark areas, whose contours change with the seasons. To explain why they do, three hypotheses have been advanced. Two are "non-vegetative," while the third ascribes the changes to some unknown type of vegetation.

First let us look at the so-called *volcanic* hypothesis. It proposes that suitably located volcanoes produce vast quantities of ash and

cinders, more or less continuously. These are carried away by the winds prevailing at the season, and are deposited in certain stable and repeatable patterns. The trouble with this theory is that it calls for volcanoes different from any we know on earth, where none erupt steadily. Also, spectrographic studies of the Martian atmosphere fail to indicate the existence of large quantities of suspended dust.

The *mineral-coloration* hypothesis, the second non-vegetative one, assumes a seasonal variation in the color of certain minerals that make up the dark areas. It is known that many "hygroscopic" or water-absorbing substances change in color, according to how much water they soak up. As the prevailing winds carry Mars' scarce water supply in seasonal cycles between the northern and southern hemispheres, the theory goes, the changing humidity of the atmosphere alters the coloration of the material covering the surface of the dark areas.

This hypothesis has several moot points. On Mars, water does not rain out and "soak" the surface—but is deposited in the form of ice crystals, as hoarfrost. And no known salts or minerals are noticeably changed in color by the minute quantities of water involved, even making the unlikely assumption that all the hoarfrost melted and was soaked up by underlying material. Finally, this hypothesis cannot explain the striking phenomenon of the dark areas' "regeneration":

Dust storms often are observed to deposit, on portions of dark areas, layers of the yellowish material that prevails in adjacent bright areas. But within a few weeks the dark area invariably regains its former contours!

Without some regenerative power (such as vegetative processes), it seems that any dark area would be buried miles deep under the yellow dust, after millions of years of dust storms.

Changing markings a sign of life?

Finally there is the *vegetative* hypothesis—the one that assumes the existence of life on Mars. The dark areas, it suggests, are covered by some form of vegetation that withers during the fall. It snaps back in the spring when the temperature rises, and

CONTINUED

the seasonal winds carry the humidity from the evaporating polar cap to lower latitudes.

The weakest point of the vegetative hypothesis is Mars' inhospitable climate. The French astronomer Gerard de Vaucouleurs, probably the greatest living expert on Mars, once described it this way: "Take a desert on earth, shift it to the polar regions, and lift it to stratosphere level—that's what it is like on Mars." And there seems to be little or no oxygen (no more than 0.15 percent, by the best estimates) in the Martian atmosphere, which consists almost wholly of nitrogen.

Can life, as we know it, exist under such conditions?

Many biologists believe that certain low forms of earthly life such as lichens, microscopic algae, and bacteria would indeed survive if transplanted to Mars.

Or perhaps—life as we *don't* know it?

But must life on Mars be limited to these lowest forms? Look at the tremendous variety of forms of life on earth—in the water, on dry land, in the air. It may well be that during millions of years of evolution, life on Mars has developed its own drastically different forms. Therefore the term, *life as we know it*, may indeed be too restrictive for the answer we seek.

In 1956 and again in 1958, the American astronomer William M. Sinton discovered certain "absorption bands" characteristic of organic molecules in the infrared spectrum of the dark regions of Mars. These bands also are observed in the spectrum of light reflected by vegetation on Earth. Many astronomers think this discovery provides almost final proof of the existence of plant life on Mars.

Nevertheless, for a definitive answer, it is still safer not to embrace this conclusion—but to await the telemetered messages radioed back by one of our forthcoming Mars probes. ■■

Dr. von Braun will consider answering questions from readers of POPULAR SCIENCE in the magazine, but he cannot undertake to answer each one by mail. Letters to him should be addressed in care of POPULAR SCIENCE, 355 Lexington Ave., New York 17, N.Y.

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How speedway tests help give you tires that can take it

Dr. von Braun Answers: "Can Astronauts Bail Out and Live?"

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Dr. Wernher von Braun Answers the Question:

Dr. von Braun, right, briefs astronaut John H. Glenn Jr., first American to go into orbit.

Mercury capsule provided astronaut with these means to bail out or end orbiting prematurely.

Can an astronaut in trouble bail out?

That depends on the situation. Obviously an astronaut, once he has been injected into an orbit around the earth, cannot simply abandon a stricken spacecraft and live. Equipped with nothing but his space suit and a reaction pistol, he cannot "retro" himself out of the orbit and hope to survive a blazing re-entry into the atmosphere, without the protection of capsule and heat shield.

On the other hand, a bail-out during the first 30 or 40 seconds of his booster rocket's ascent would subject an astronaut to no more severe an aerodynamic shock than in parachute ejection from a fast aircraft.

Because of the wide spectrum of flight conditions encountered during a typical orbital mission, the designers of the Mercury capsule, our first manned spacecraft, decided to adhere to the ground rule that the astronaut shall stay with the ship, come what may. Instead of providing emergency means for the astronaut to eject himself into what might be a marginal or deadly environment, they furnished all conceivable safety features to bring the capsule itself to

CONTINUED

earth intact, with the astronaut safe inside.

Q ***What is the emergency procedure during the launch phase?***

A In case of a sudden emergency during the boosted ascent into orbit, the main requirement for safe capsule recovery is a suitable mechanism for rapid separation of the capsule from the boost rocket.

In Project Mercury this mechanism consisted of a Launch Escape Tower extending forward from the top of the capsule, with a powerful short-burning solid-fuel escape rocket in its tip. Upon activation by the astronaut, the escape rocket would be fired while a set of explosive bolts would sever the capsule from the aborting Atlas rocket. Simultaneously the Atlas engines would be shut down—and the escape rocket would hurl the spacecraft and its occupant away from the booster with a brutal 20-G blast. The main purpose of this escape rocket was to put a safe distance, as quickly as possible, between the spacecraft and the stricken booster—which, like a jet plane hit by enemy fire, conceivably might explode at any moment. In case a dangerous fire developed while the Atlas rocket was still sitting on its launch pad, the Mercury escape rocket was powerful enough to carry the capsule to a safe altitude for deployment of the capsule parachute.

Q ***What can an astronaut do if trouble strikes later?***

A About 2½ minutes after lift-off, with the two Atlas *booster* engines already dropped off and the flight continuing under *sustainer* engine power, the Launch Escape Tower is jettisoned. By now, the Mercury-Atlas combination has risen above the sensible or perceptible atmosphere, and a failure in the complex Atlas control system would no longer lead to structural breakup and resulting explosion. Aerodynamic forces during an emergency separation have likewise become negligible.

As a result, separation can now be effected simply by shutting off the Atlas sustainer engine—and gently pushing the capsule away from the Atlas with the help

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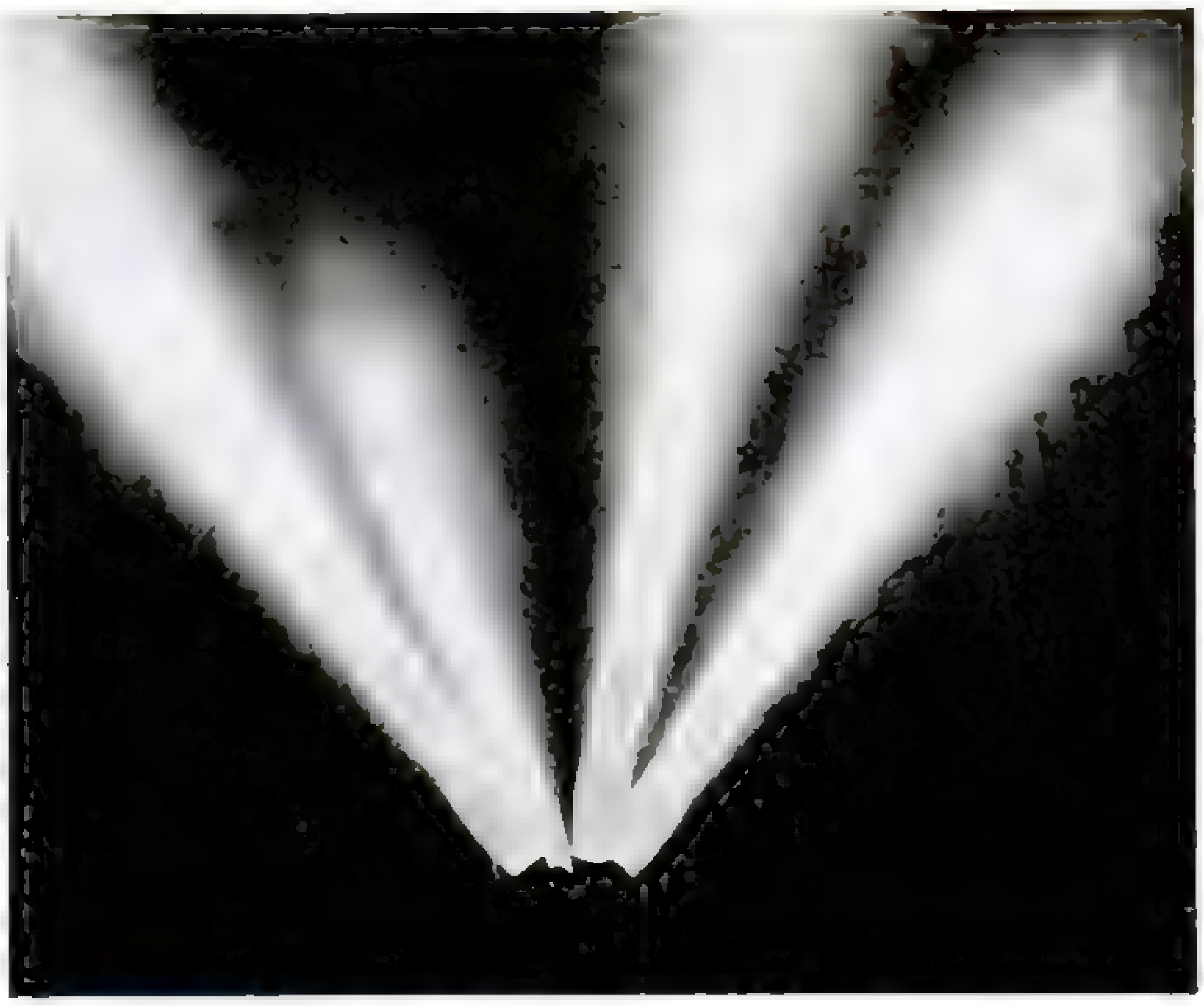

Escape rocket for coming three-man Apollo moon capsule, upside-down on test stand, gets flaming trial. Many times size of Mercury version, it has four flaring nozzles instead of three.

of a set of rather weak "posigrade" rockets. Since the spacecraft has not yet attained orbital speed, it will soon drop back into the denser layers of the atmosphere. The astronaut must therefore turn his capsule around so that its blunt heat shield will be facing the onrushing air. This places him in a safe condition for re-entry.

About five minutes after lift-off, if no emergency has developed during the ascent phase, the Atlas-Mercury system goes into orbit. Immediately the capsule is separated from its booster and turned around. This, again, puts it in a safe re-entry position.

But while re-entry into the atmosphere is the automatic consequence of shutting off Atlas power in an emergency at *suborbital* speed, return into the atmosphere from *orbital* flight always requires a separate retro-fire maneuver to reduce the initial orbital speed. The rocket power for this maneuver is provided by the so-called retropack strapped to the heat shield of the Mercury capsule—the same retropack that normally ends an orbital flight.

Thus, emergency descent from an orbit is simply a premature termination of the original flight plan.

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Popular Science

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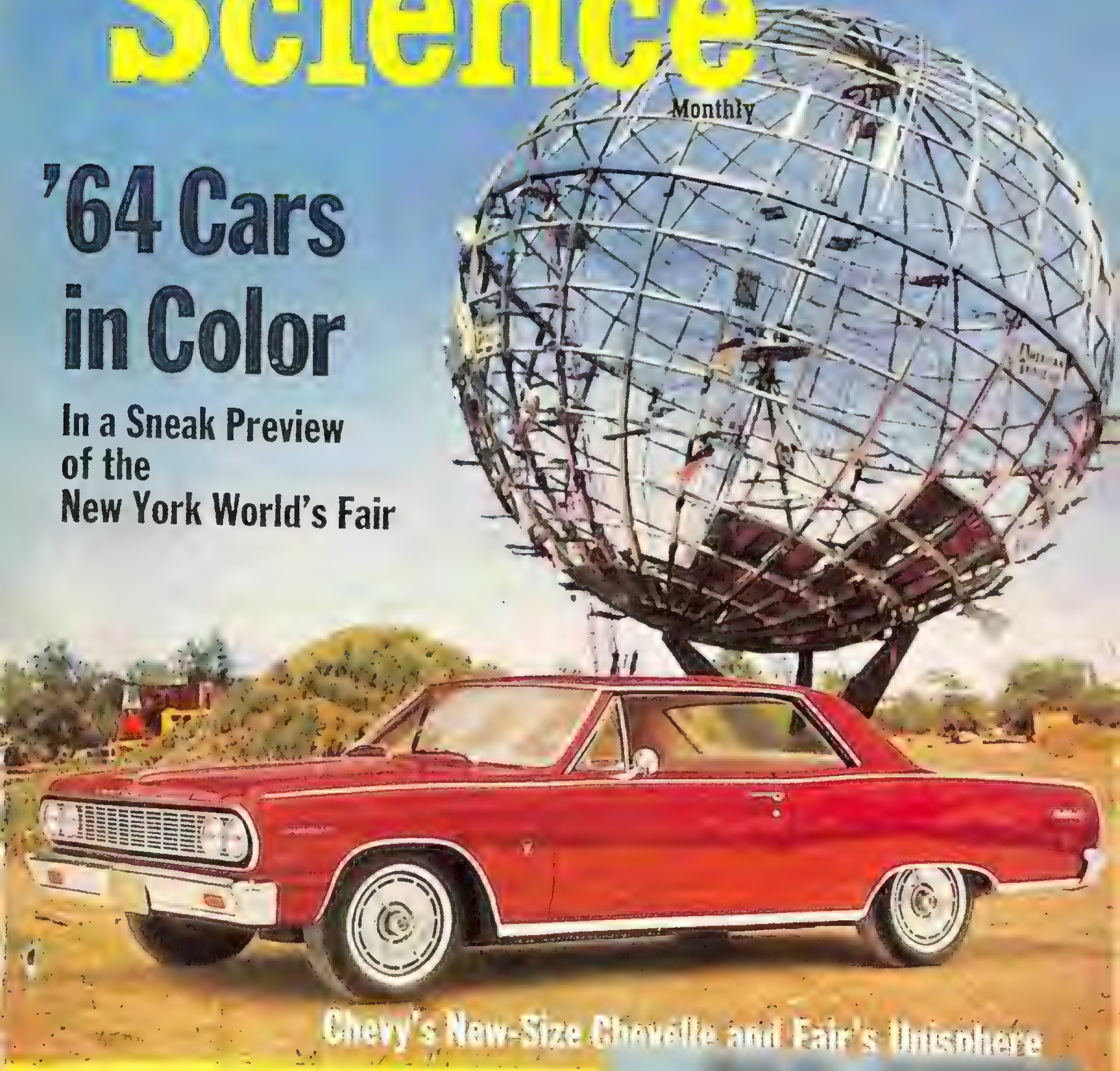
ANNUAL NEW-CAR ISSUE

'64 Cars in Color

In a Sneak Preview of the New York World's Fair



Chevy's New-Size Chevelle and Fair's Unisphere

PS Test Reports on BOATS–TOOLS–TV

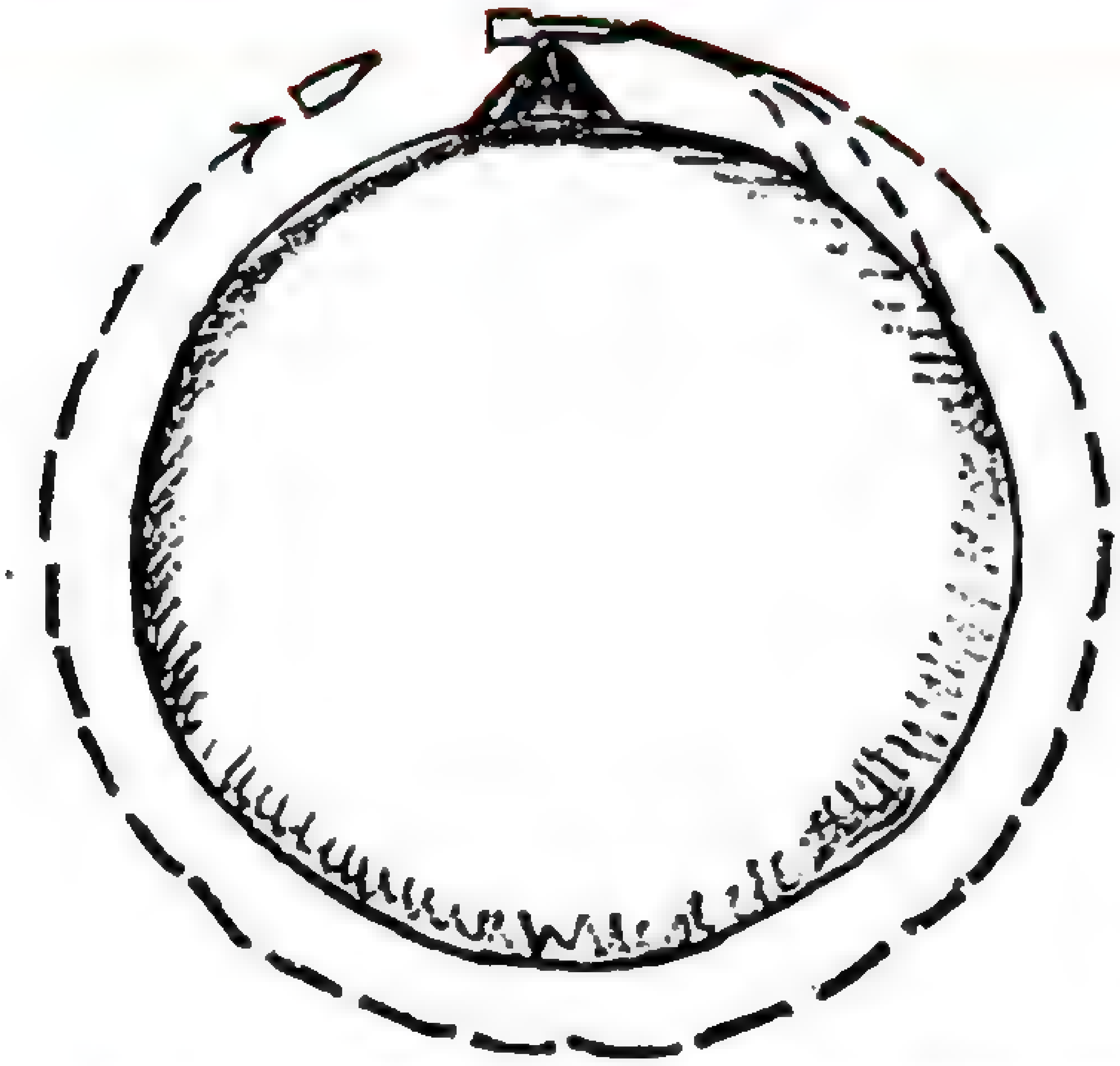
New Pola

How to Make Your Own Plastic Bearings

Dr. von Braun, right, and Robert C. Seamans Jr., Associate Administrator, NASA, discuss task of a spaceman. Ears of the one in background don't burn—he's just a dummy in a space-capsule exhibit.

Dr. Wernher von Braun Explains:

Why a Satellite Stays Up



Q ***What makes a satellite go into an orbit?***

A Imagine yourself standing on a high mountain peak, well above the atmosphere, firing a gun in a horizontal direction. (See my sketch above.) The shell, after leaving the gun barrel, will first fly horizontally. But soon the earth's gravitational pull bends the trajectory downward, as in the shortest of the paths in the sketch.

Reload the gun with a more powerful charge and the shell will fly farther, as shown by the next-longer path in the sketch. Its trajectory will be less deflected because the centrifugal force (as it follows the earth's curvature) is increased by its higher speed, and more effectively counteracts the earth's gravitational pull.

If you could use a charge powerful enough to give your shell a velocity of about 4.9 miles a second (17,600 m.p.h.), *the curvature of the downward-bent trajectory would become equal to the curvature of the earth.* The shell would keep flying and flying, and about 85 minutes later you'd better take cover—because the projectile, having gone all the way around the earth, would approach you from behind and hit the breech of the gun in the rear. The shell would have traveled in a circular orbit, the longest and globe-circling path in my sketch. If you don't believe it, ask John Glenn, Scott Carpenter, Wally Schirra, or Gordon Cooper.

In more general terms, this is what makes an orbit tick, and decides what kind of an orbit it will be:

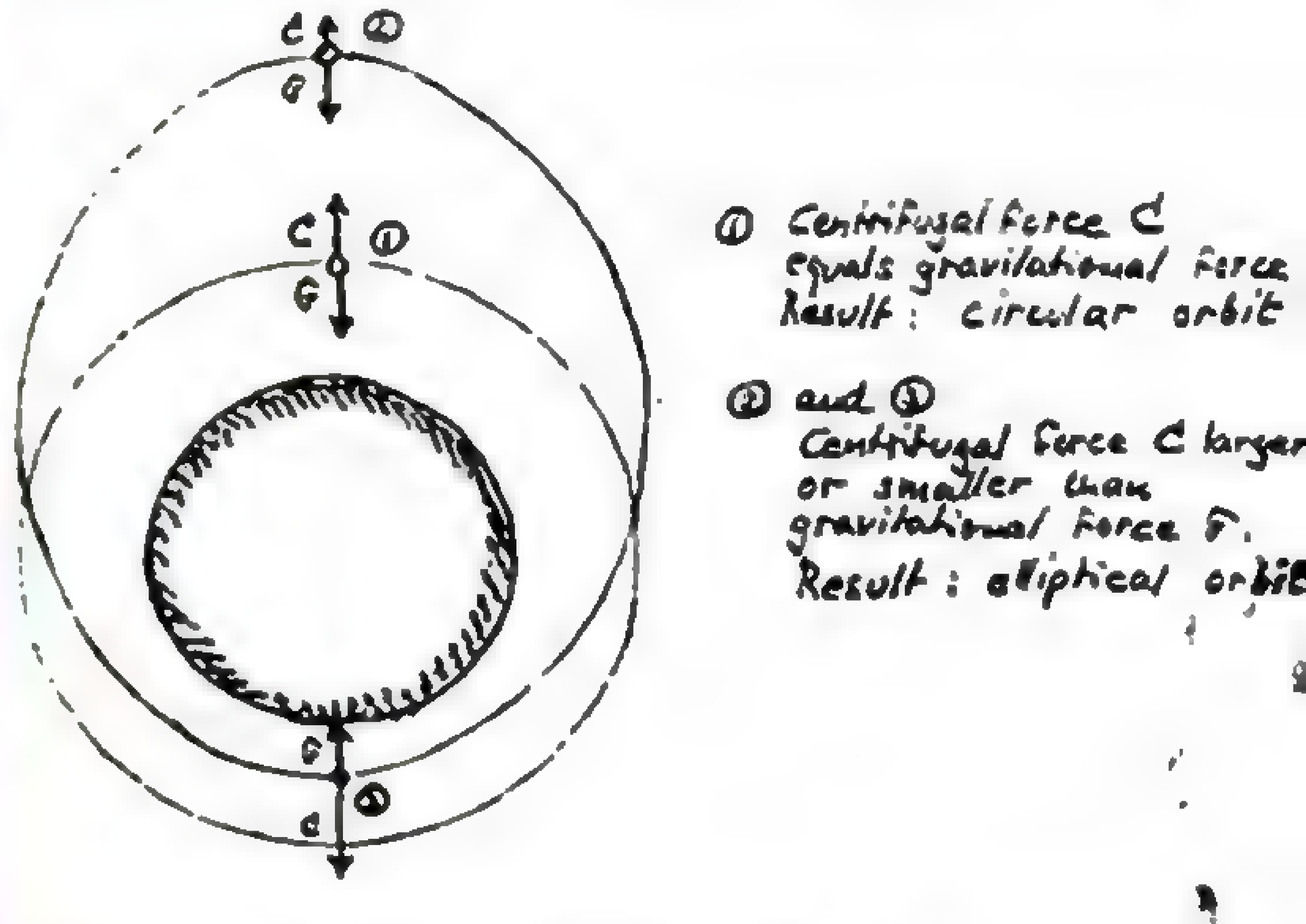
A circular orbit occurs whenever a small

CONTINUED

Dr. Wernher von Braun continued

mass, traveling through the gravitational field of a big one, happens to have a speed at which the centrifugal force is precisely strong enough to balance the large body's gravitational pull. This precision exists, to a high degree, in the orbiting of the moon around the earth, and of the earth and Venus around the sun.

If the balance between gravitational and centrifugal force is not perfect, but the centrifugal force is strong enough to pre-



vent a direct collision, the small body will describe an elliptical path around the large one. Comets follow elliptical orbits around the sun.

The second of my sketches sums up the conditions that will give rise to a circular or ellipitical orbit, respectively.

Q ***What is a synchronous satellite?***

A A synchronous satellite (such as our recently launched Syncom No. 2) is a spacecraft coasting from west to east in a very high circular orbit, with a period of revolution of exactly 24 hours. An additional requirement is that the plane of the orbit must coincide, at least fairly nearly, with the plane of the equator.

Since the earth likewise revolves about its axis from west to east once every 24 hours, and since the earth's axis is at right angles to the plane of the equator, a synchronous satellite will appear to stand still, forever—directly above one particular spot on the equator. (Or if it has been launched on a path somewhat inclined to the equator, as in the case of Syncom No. 2, it will appear to move back and forth

CONTINUED

Dr. Wernher von Braun continued

with a figure-8 motion above such a spot. As is required for a 24-hour period of revolution, its height is always 22,300 miles above the earth's surface.

Synchronous satellites are of great interest for global communications. Because of its great distance from earth (about six earth radii), a 24-hour satellite is simultaneously visible from a vast portion of the globe. For example, such a satellite "hovering" above the Amazon delta in Brazil would be in direct line-of-sight contact with places as far apart as Seattle, Thule (in Greenland), London, Rome, Cape Town, Buenos Aires, Los Angeles, and parts of Antarctica. As a never-setting variety of the famous Telstar satellite, it could serve as a permanent telephone or television relay station, linking North America to Europe, Africa, and Latin America.

Such a communications service would use microwaves—which can be beamed up to the synchronous satellite with the help of huge ground-based dish or horn antennas. The satellite itself need not have a directional antenna. It simply feeds the received signal into a solar-powered transmitter, and retransmits the amplified signal back to earth, on a different frequency.

Microwaves permit the use of a great number of adjacent frequencies, without cross talk. Thus a single synchronous satellite can handle many simultaneous telephone conversations and television programs.

Three synchronous communications satellites in the same orbit, spaced 120 degrees apart, could cover the entire earth (except for the areas around the North and South Poles, where all three satellites would be a trifle below the horizon).

Due to the satellites' enormous altitude, the travel time of the electronic signals from the earth's surface to the satellite and back will amount to almost one-third of a second. While this is immaterial for television, the time lag will be quite noticeable in telephone conversations. ■ ■

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SPECIAL GLUE ALLOWS THIS TO BE PEELED OFF WITHOUT DAMAGE TO COVER

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Facts—Features—Performance

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How to get started with

HI-FI KITS

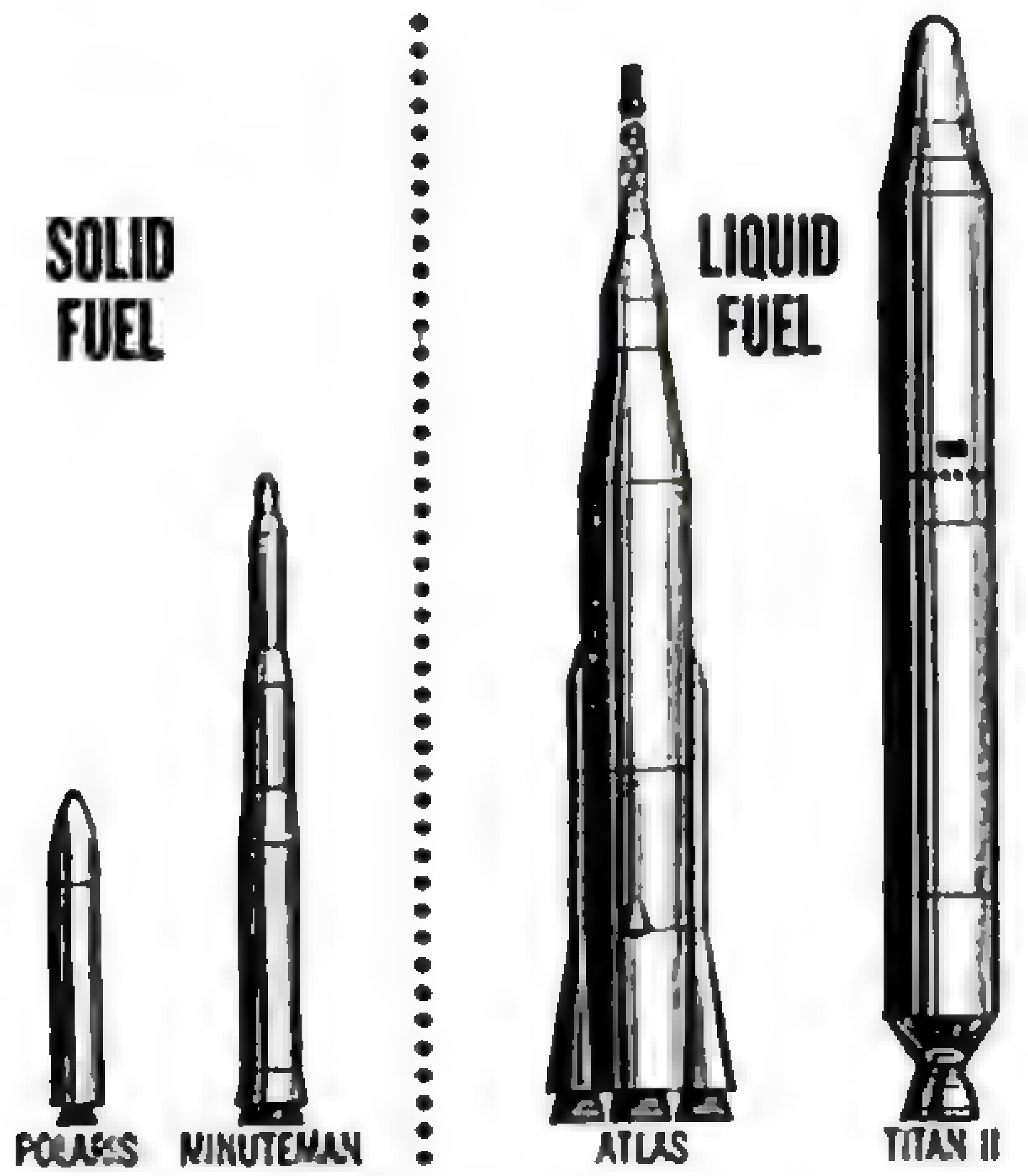
PS Test-Drives the "IMP"

New Crawl-Anywhere Car

Dr. von Braun, center, shows Congressmen a model of Saturn V man-to-moon rocket engine.

Q

Dr. Wernher von Braun Weighs the Pros and Cons



Q ***Which is better, a liquid-propellant or solid-propellant rocket?***

A That depends entirely on the application. Just as a gasoline engine has advantages and disadvantages compared to a diesel engine, the liquid rocket engine is superior to the solid rocket engine in some applications, and inferior in others. And just as the two types of piston engines are still around, after half a century of heated debate about their pros and cons, it is most likely that 50 years from now there will still be both liquid- and solid-propellant rocket engines in practical use.

The advantages of the liquid-propellant rocket—of which the Atlas and Saturn are examples—lie in its higher performance, its simple shutdown and restart capability, and the fact that it lends itself readily to a number of important control features. For example, the thrust of a liquid-propellant rocket can be varied at will, by throttling the propellant flow, and the rocket can easily be steered in flight by swiveling the relatively small engine or engines.

The advantages of the solid-propellant rocket—the Minuteman and Polaris are of this kind—lie in its inherent simplicity. It need not be fueled just prior to launching. It needs no pressure system or pumps to feed the propellants from the tanks into the combustion chamber, since the rocket's case combines the functions of both. The resulting simplification and speedup of launch preparations makes the solid-propellant rocket especially attractive for military applications where quick response may be vital.

What are the solid propellants?

The Chinese, who are credited with the first demonstration of rockets in the 13th century, probably used black powder. That age-old concoction of charcoal, sulfur, and saltpeter was faithfully used in all war, signal, and ship-rescue rockets until the end of World War I. Only in 1918 did the American, Robert H. Goddard, first try to burn *smokeless powder* in rockets. And only after World War II did the chemical industry come forth with high-energy composite propellants that enabled solid rockets to in-

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vade the field of long-range ballistic missiles, hitherto held uncontestedly by the more-powerful liquid rockets—and to force the liquid rockets right out into the even-more-demanding field of outer space.

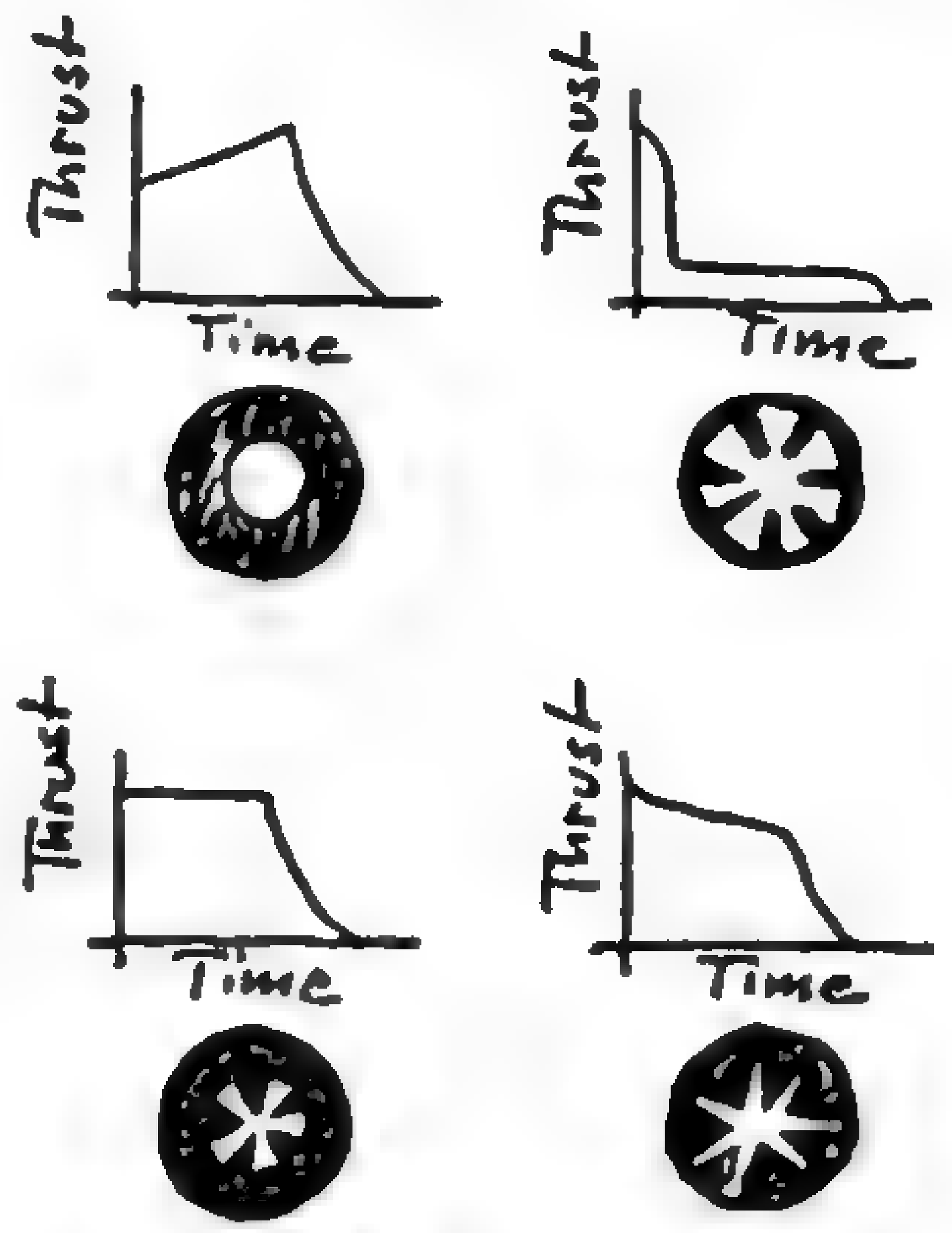
Composite propellants consist mainly of a more or less rubbery fuel binder, in which saltlike crystals of oxidizing agents are embedded. A typical mixture may contain as much as 80 percent by weight of these particles and still retain an amazing degree of plasticity.

There are several types of fuel binders, which differ in performance, price, high and low temperature qualities, storability, and so forth. The one quality they all have in common is long names. There are vinylpolyester, polyurethane, and polyvinyl chloride binders, just to name a few. The oxidizing agents, not to be outdone, bear labels such as ammonium perchlorate, ammonium nitrate, or potassium perchlorate. To increase combustion temperature and fuel performance, aluminum powder is sometimes added to the mixture. Finally, composite propellants usually contain a small percentage of additives to serve as combustion catalysts, chemical stabilizers, or flash suppressors, or to provide certain physical properties otherwise lacking.

Q ***What are the principles of designing solid-propellant rockets?***

A Probably the most important rule is Piobert's Law, which states that the flame front always eats its way into the solid propellant in a direction normal (perpendicular) to its surface. Thus if we fill a tube completely with rocket propellant, and light it at one end, the propellant burns down the length of the tube like a cigarette.

Suppose we drill a hole all the way along the center line of the "grain" (that's what solid-rocket men call the propellant loaded into the "case"). Then if we flash an igniter jet down the length of this tunnel, the flame propagates in a radial direction, and will finally reach the outer wall at the very instant all the propellant is consumed. With the increasing diameter of the tunnel, the combustion surface increases. Consequently, the combustion gas produced per second, and the thrust generated by it, will be smallest at the moment of ignition and largest at the moment of burnout.



Grain cross sections for a number of desired Thrust-time curves

Usually a solid-propellant rocket is designed especially for a kind of performance most likely to be wanted. This means that there is a certain desired relationship between thrust and time. For instance, there may be a requirement to have the maximum thrust at takeoff, when the rocket is heavy, and to have the thrust taper off as it gets lighter. To meet such specifications, rocket designers have developed all kinds of sophisticated grain cross sections, along which the flame front may proceed, to create the desired combustion surface at any given instant (see my sketch). Occasionally this method is further refined by the use of two or more layers of propellant with a different "linear burning rate"—the speed at which the flame front eats its way through the propellant, in inches per second.

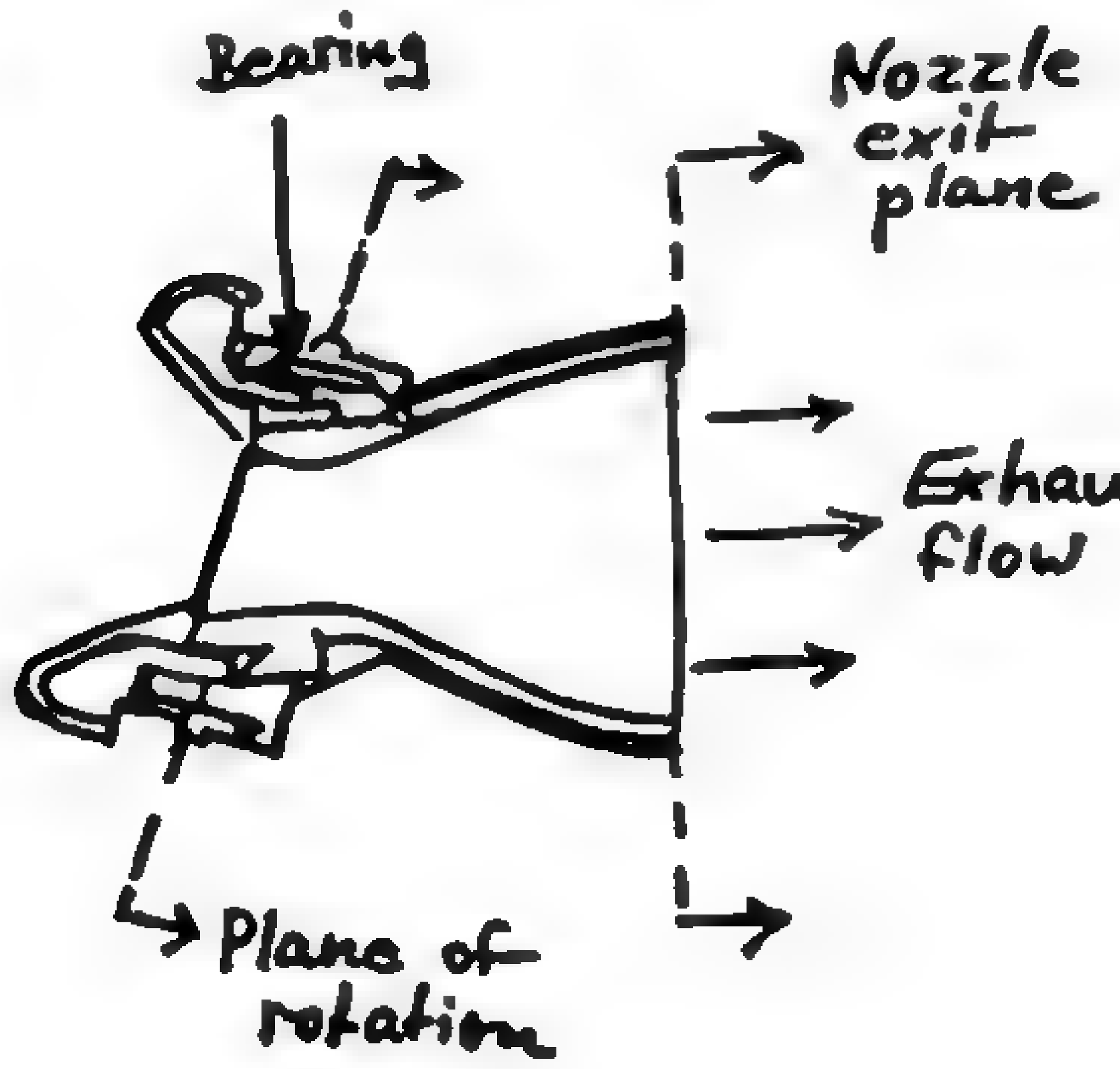
Steering solid-propellant rockets

Control of the rocket in flight can be accomplished in a variety of ways. Small ballistic, short-range "barrage" rockets are usually fin-stabilized like an arrow, or spin-stabilized like a bullet. Larger medium, long-range, or antiaircraft rock-

ets with sophisticated inertial or radio guidance systems, however, need a suitable mechanism to convert the electrical steering signals into forces powerful enough to change the rocket's flight path. Aerodynamic control surfaces alone are usually not sufficient; they are ineffective right after takeoff, as well as in the vacuum of outer space. So flat jet vanes or pivoted ring-shaped "jetavators," which can be tilted so as partially to deflect the jet from the nozzle, are often used.

Some of our large solid-propellant long-range ballistic rockets utilize several parallel nozzles through which the gases from the same rocket engine discharge. In this case, "thrust vector control" is often accomplished by rotating the nozzles. The plane of rotation of such a nozzle is skewed to the nozzle exit plane (see my sketch). The sealing and friction problems involved are easier to overcome than with tiltable nozzles.

Just as important as thrust vector control is the ability to shut off the rocket thrust of a ballistic rocket, after the necessary velocity for the desired range has been reached. This may be done by "thrust termination"—for instance, by blowing off the entire exhaust nozzle, so that the abrupt pressure drop extinguishes the fire. Another method uses "thrust reversal": A number of ports are opened, usually by blasting their membrane covers away. Some of the escaping exhaust gases discharge in the forward direction, with their total backward thrust exceeding the remaining forward thrust. Since the warhead is simultaneously released, this technique in effect backs the spent rocket away from the nose cone, at the moment the desired speed is reached.



Casings of solid-propellant rockets are usually made of high-strength steel, titanium, or wound fiberglass.

Q ***What is a hybrid rocket?***

A It is a crossbreed between a liquid-propellant and a solid-propellant rocket, in that it uses one liquid- and one solid-propellant component. Usually it has a solid-fuel grain against which a liquid oxidizer is sprayed. Sometimes the arrangement is the other way around.

Hybrid rockets offer a number of potential advantages. Their nozzles can be cooled by the liquid component, which may result in substantial weight savings over the heavy uncooled nozzles of long-burning solid-propellant rockets. Then, the thrust of a hybrid is easily controllable by throttling the liquid component. With the same throttling valve, the rocket can also be turned off competely, and started again—the latter trick still being beyond the reach of any solid rocket.

Certain liquid components suitable for hybrid rockets—whether fuel or oxidizer—can also be used as monopropellants. That is, on being fed through a suitable "catalyst bed," they decompose into a moderately hot gas. This feature can be used for numerous auxiliary purposes: tank pressurization, pneumatic-control pressure, attitude-control nozzles, vernier thrust for precise guidance maneuvers.

For all their potential, hybrid rockets still have failed to find much practical application. Many designers feel that they merely share the disadvantages of the low-energy solid-propellant rockets and the highly complex liquid-propellant rockets, and thus are not too attractive. Others believe that there will be applications in which the hybrid rocket will prevail. ■ ■

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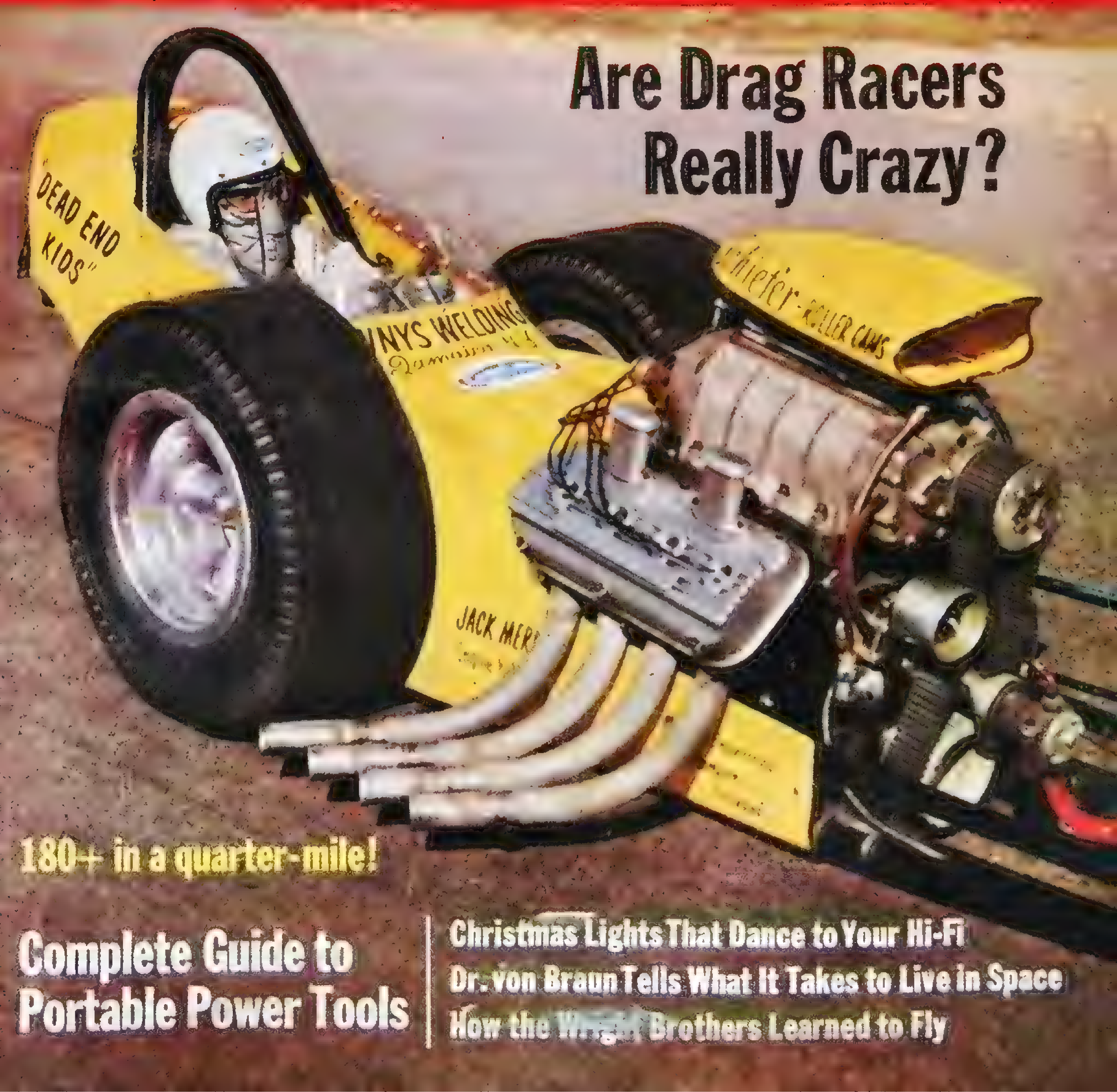
The REAL Causes of Death by Car

A startling new report by Harvard University

What's New at the Hardware Show



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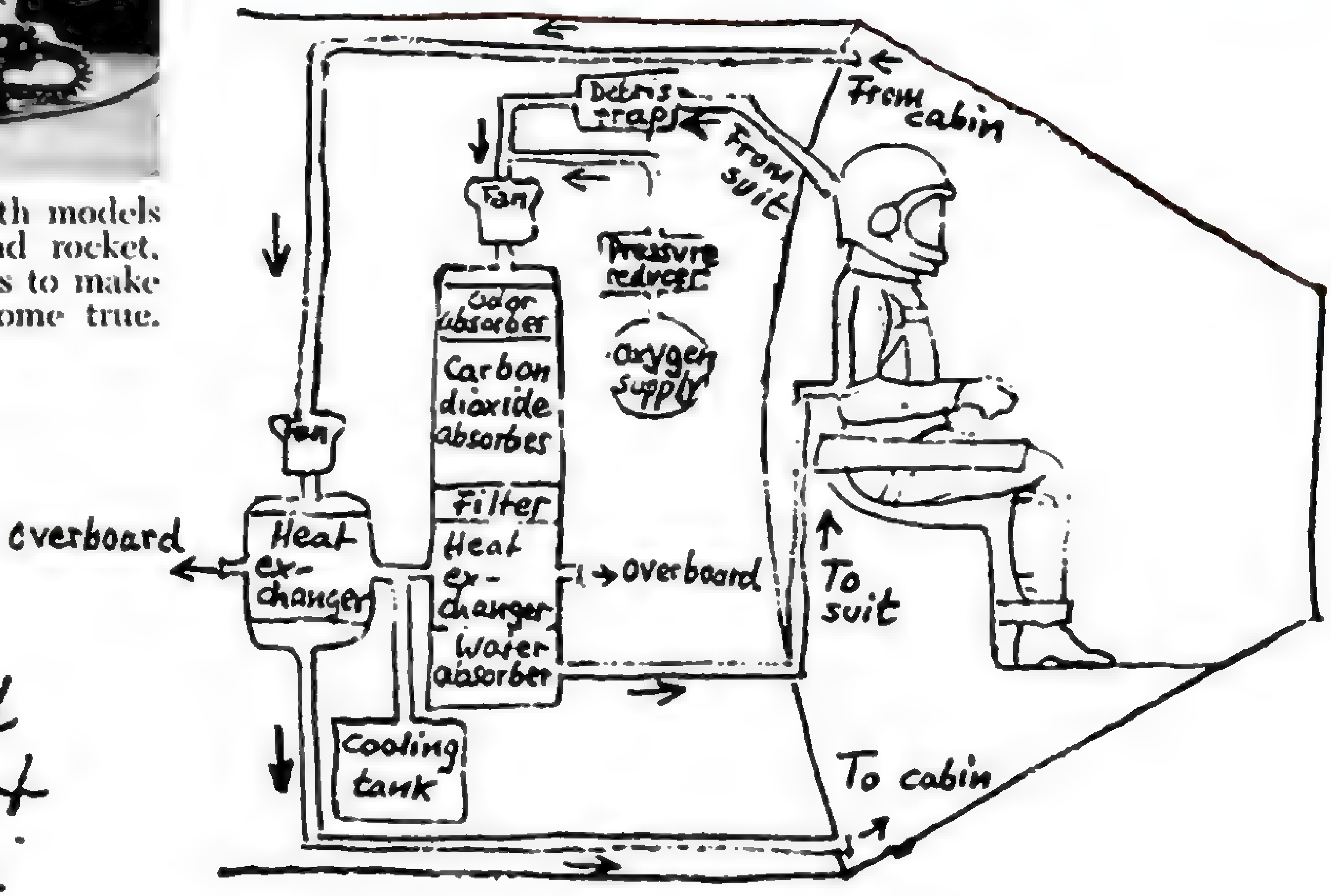
Christmas Lights That Dance to Your Hi-Fi

Dr. von Braun Tells What It Takes to Live in Space

How the Wright Brothers Learned to Fly

Dr. Wernher von Braun Tells
What It Takes to Survive in Space

At desk adorned with models of moon capsule and rocket, Dr. von Braun works to make outer-space travel come true.



Semiclosed life support equipment used in Mercury spacecraft

Q ***What equipment and supplies does an astronaut need to survive in outer space?***

A Besides food and drink, he needs:

- A pressurized spacecraft cabin, with means for replenishing oxygen, removing carbon dioxide and odor, and controlling temperature and humidity.
- A contour seat, for the high accelerations and decelerations encountered during launch, mid-course maneuvers, and reentry.
- A pressure suit, as protection in case of cabin-pressure loss, and as mandatory equipment if the mission ever requires the astronaut to go outside his spacecraft.
- Sanitary accommodations in accordance with the duration of the mission.
- Some radiation protection, dependent on the length of the mission and the flight profile. For example, an extended stay in the Van Allen Belts, or a long interplanetary voyage, demands more radiation protection than a low-altitude earth-orbit flight, which can be recalled at short notice in case of a dangerously powerful solar flare.

For very long outer-space flights, a degree of bodily mobility is also likely to be necessary. Some equipment for physical exercise—possibly of the familiar coil-spring kind—may prove indispensable, too.

Among space medical men, opinions still vary as to whether the zero-gravity condition, always prevailing during the unpowered stretches of a space voyage, will turn out to be acceptable for extended periods. Some believe the astronauts will need an "artificial G environment" in such cases.

CONTINUED

One scheme would provide a separate "reconditioning capsule" attached by a cable to the ship's main body, and slowly spinning around it; in this capsule, centrifugal force would then simulate gravity.

Q ***Beyond what altitude is it necessary to provide an artificial cabin atmosphere for spacemen?***

A The average person needs some life-support equipment above about three miles. At this altitude, along with the decreased *total* atmospheric pressure, the *partial* pressure of the air's oxygen has sunk so low that the lungs cannot absorb enough of it. Hypoxia, or oxygen deficiency in the blood, results. Breathing pure oxygen (at the same reduced total atmospheric pressure) raises the oxygen partial pressure, and provides a ready remedy.

At an altitude of 4½ miles, the unprotected human body faces another difficulty. By now, atmospheric pressure has dropped to a point where the nitrogen dissolved in our blood starts bubbling out. The physics of this is identical with what happens when we open, and thus depressurize, a warm Coke bottle. The effects, however, are decidedly more severe. Some nitrogen bubbles, as the pulsating blood stream washes them through the body, may get trapped in corners such as elbow and knee joints. As the ambient pressure keeps falling, the trapped bubbles expand further and may block off an artery. This causes painful aeroembolism, better known as the "bends." Thus, beyond a limit of 4½ miles or so, pressure cabins or pressure suits (at least, partial-pressure suits), or both, must be provided.

Ten miles up is another biological milestone. By now the atmospheric pressure has become as little as the combined partial pressures of water vapor and carbon dioxide, two substances always present in our lungs. No matter how much pure oxygen we try to breathe, the air sacs of the lungs are now completely filled with this mixture of water vapor and carbon dioxide, and no oxygen can enter the blood stream. This condition is called anoxia.

Just a little higher up, the unprotected, tortured body would virtually boil over. At an altitude of 12 miles or so the air is

so thin that the boiling point of our body fluid drops to around 100 degrees F., which is about our body temperature. Bubbles now form wherever body fluids are openly exposed on surface areas of the body, such as the mucous linings of the mouth and eyes.

While all these milestones of increasing biological hazards had tremendous practical significance in aviation, their importance for spacecraft is actually quite limited. A spacecraft's life-support system must be designed for an extended stay in completely airless outer space, anyway. In less than one minute a manned rocket clears the lower atmosphere, so there is not much chance to take advantage of the less-demanding conditions prevailing there. Hence it does not matter too much to the designer whether his craft is five or 50,000 miles high. He has to provide adequate life support for the most demanding condition, a perfect vacuum outside.

Q ***What kinds of life-support systems are there?***

A We must distinguish between three different types of systems: open, closed, and a crossbreed called semiclosed.

An open system simply delivers fresh air or oxygen to a breathing mask, and vents exhaled air overboard. It makes no attempt to retain and recirculate the unused oxygen—or the 79 percent nitrogen in exhaled air. The aqualung is an example of an open life-support system, using air. The oxygen-mask system in unpressurized aircraft is an open system using pure oxygen.

A closed life-support system attempts to duplicate in capsule form the complete miraculous "ecological system" that nature operates on earth: The carbon dioxide that man and beast exhale is absorbed by plants and helps them grow and develop through an intricate process called photosynthesis—the fundamental process of life on earth. Light energy from the sun converts the carbon dioxide into plant-building carbohydrates, while oxygen is released into the air. Men and animals breathe this oxygen, and eat the plants and the fruits they bear, while their body wastes fertilize the soil on which the plants grow.

Very promising attempts have been made

CONTINUED

to duplicate nature's grand scheme in the laboratory. Most experimenters use certain strains of algae as the plants for the ecological cycle.

Obviously the advantage of the open life-support system lies in its simplicity. But it is very wasteful, and the weight of the air or unused oxygen vented overboard becomes prohibitive for space-flight missions of more than a few hours.

The closed system on the other hand is complicated and relatively heavy. But it is ideally suited for long operating periods, because it puts the sun to work to enable us to reclaim virtually all of the wastes. We can expect such closed systems to be used in manned interplanetary expeditions, and at a permanent base on the moon.

For the Mercury spacecraft's flights, of up to a day and a half, a semiclosed system using a pure-oxygen atmosphere was selected. This system is best explained with the help of my sketch (which I made from a description published by the maker, The Garrett Corporation of Los Angeles).

How Mercury life-support system works

As shown, there are two almost independent recirculation cycles—for the pressurized cabin and the pressurized space suit. Water-cooled heat exchangers, inserted in both cycles, dissipate the heat generated by the astronaut himself and by all the electrical gear. A supply of oxygen—carried in gaseous form at 7,500-pound pressure—replenishes the suit cycle with fresh oxygen, to the same extent that an absorber removes exhaled carbon dioxide.

This system proved entirely adequate for the limited duration of the Mercury flight missions. Many medical experts believe, however, that for flights of much longer duration it will be necessary to replace the semiclosed oxygen system with a semiclosed air system—that is, a system where the oxygen is diluted with nitrogen or other inert gases. According to Soviet reports, the man-carrying Vostok spacecraft all used semiclosed air systems.

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How to Restore a Player Piano

Dr. von Braun on "Automatic Checkout"

Dr. von Braun continues as PS space expert in 1964

Asked to name one outstanding figure in rocket and space technology today, layman and scientists alike would be likely to think first of Dr. Wernher von Braun. As Director of the National Aeronautics and Space Administration's Marshall Space Center at Huntsville, Ala., where our great Saturn V moon rocket is taking shape and where still more-advanced research projects are under way, he is playing a leading role in the thrilling adventures of the Space Age. It would be hard to imagine a more preeminent authority on the new and news-making science of astronautics, which may be expected to provoke exciting headlines in the year just begun.

Popular Science therefore takes particular pleasure in announcing that Dr. von Braun, who last month completed a year of writing for this magazine, has agreed to continue as a regular contributor for a second year. In this issue and coming ones of 1964, PS is privileged to present Dr. von Braun's authoritative answers to space questions from our readers.

Dr. Wernher von Braun tells how

Automatic Checkout Gives Rockets the Green Light

Q *What is automatic checkout of a space vehicle?*

A It is a method to speed up the checkout of the intricate mechanical and electrical systems that make up a multi-stage space rocket, the spacecraft in its nose, and the supporting launch equipment on the ground.

In the past, the checkout of these systems was usually a slow and rather tedious step-by-step procedure. As space vehicles grew in complexity, more and more people became involved in this operation, and the time needed for pre-launch preparations and for the actual countdown got longer and longer.

Automatic checkout was first introduced in ground- and air-launched guided-missile systems. It is used extensively for all of our latest manned and unmanned space vehicles.

The basic idea behind automatic checkout is simple. Suppose we have a hospital with 500 patients but only one nurse. If she were to attend all the patients by visiting 500 private rooms, some patients might die for lack of immediate attendance. To solve this dilemma, suppose we now wire up our 500 patients for important clinical information: fever temperature, pulse rate, breathing cycle, skin temperature, brain-wave emissions, and the like. The electrical outputs of all these gauges, which are attached to the patients' bodies, are fed into a central electronic computer.

In the magnetic memory of this computer, detailed information has been stored about the permissible upper and lower limits of all the collected data. For example, a body temperature between 97.8 and 99.4 degrees F. may be

SIX DAYS TO DALLAS—"We've come a long way."

It was a beautiful, cloudless morning, with a crisp breeze blowing in from the ocean, when President Kennedy's big jet touched down on the Skid Strip at Cape Canaveral—now Cape Kennedy. The day was Saturday, Nov. 16, 1963. In a crowded two hours he inspected what had changed at the Cape since February, 1962, his last visit. There was the gleaming Atlas Centaur II, which flew successfully 10 days later. There were astronauts Cooper and Grissom to explain the two-seater Gemini spacecraft scheduled for its first unmanned flight early in 1964. There was the huge Saturn I Flight #5 undergoing final checks for the first two-stage launch, due before Christmas.

In the Complex 37 blockhouse, Dr. George E. Mueller, NASA's Associate Administrator for Manned Space Flight, gave a rundown on his program. He had hardly finished when the trim, sun-tanned President jumped up and grabbed an 18-inch model of the Redstone/Mercury, the bird Shepard and Grissom rode on their suborbital flights. He held it up to the huge, six-foot model of the Saturn V/Apollo which will carry our first astronauts to the moon and back.

"Are these two models the same scale?" the President asked. When he heard they were, he exclaimed with a boyish smile, "Looks like we've come a long way!"

Outside the blockhouse, in front of the

President Kennedy studies the Saturn at Cape Canaveral, Nov. 16, 1963.

towering Saturn I, I briefed him on the purpose of its forthcoming flight. I said that, if successful, this rocket would loft the heaviest load ever orbited. The President was obviously pleased, for five days later, in a speech at Brooks Aerospace Medical Center in Texas, he said that from what he'd seen at Canaveral he was certain the time of Soviet superiority in launch rockets was drawing to a close. From Brooks he flew on to Dallas. . .

Wernher von Braun

considered normal for the patient in Room 278, while 100.6 degrees may indicate that he is running a fever. The computer would alert the nurse to this irregularity and even provide her with a little print-out, which might read "R 278, T + 2.0," meaning that the patient in Room 278 has a temperature two degrees higher than the average of 98.6 degrees F.

A complex space vehicle such as Saturn V/Apollo consists of virtually thousands of "patients" whose pulse and fever temperature must be continuously monitored, to make sure that we don't launch a vehicle with a sick subsystem.

Readiness is repeatedly checked

Due to the rapidity of automatic checkout, it is possible to run a complete check prior to committing the vehicle to launch, and to repeat the checkout several times during the actual countdown.

Automatic checkout of a space vehicle is not limited to the mere sampling of "status readings." The method is rendered vastly more effective by the technique of subjecting the patient to "diagnostic" electrical stimuli, strategically applied, and evaluating his response to them.

Q ***How does the technique work?***

A It may be illustrated by the example of a rocket's autopilot.

Suppose the rocket encounters some atmospheric turbulence during its flight through the air. Just like an airplane being tossed about in rough air, the rocket will yield a bit, at first, to a wind gust that is trying to throw it off course. But proper control-stick deflection by

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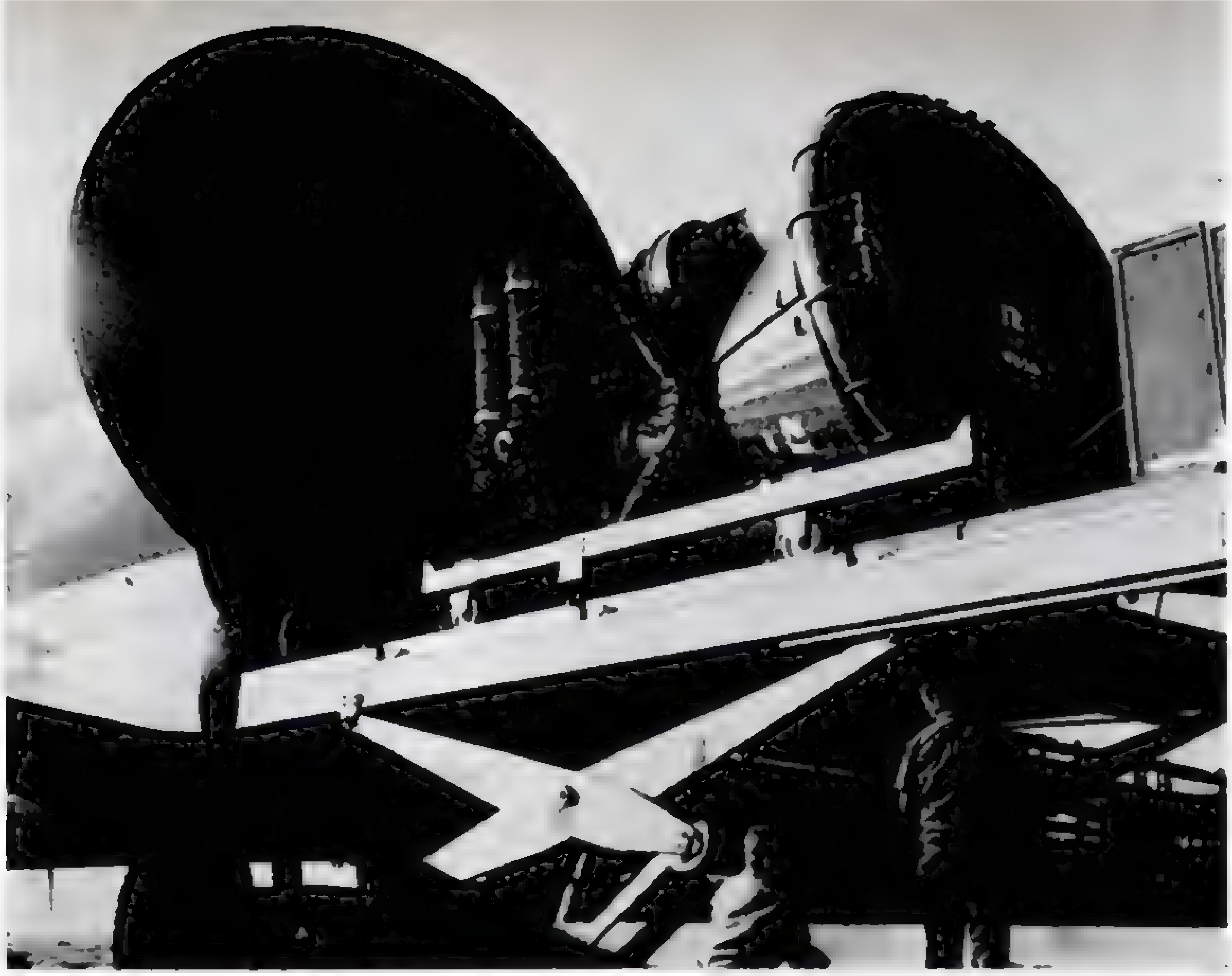

First production model of mighty F-1 rocket engine for manned U.S. lunar missions goes aboard plane at Rocketdyne's Canoga Park, Calif., plant for delivery to Marshall Space Flight Center. Cluster of five F-1s will yield 7,500,000 pounds of thrust for first stage of Saturn V rocket that launches Apollo spacecraft. Automatic checkout, both before and during countdown, will assure that all systems are working properly before rocket lifts off.

pilot or autopilot will soon compensate for the disturbance.

In a rocket's autopilot, the initial deflection from the rocket's heading will manifest itself in the form of a deflection angle between the rocket's axis and the space-fixed orientation of a gyroscope. This deflection produces a corresponding electrical signal. Through the complex circuitry of a control computer, the signal will finally cause a set of hydraulic actuator pistons to deflect the swivel-mounted rocket engines. The change in direction of their thrust will restore the rocket's flight path.

To check this entire control circuit, the checkout computer simply injects into the control computer an electrical stimulus signal that imitates an electrical deflection signal from the gyroscope. This makes the control computer *think* there is a deflection angle at the gyro.

Responding to the stimulus signal, the rocket-borne control computer processes the instruction, and causes the actuators to deflect the rocket engines.

The checkout computer compares the stimulus and response—the electrical stimulus signal, and the electrically indicated engine deflection that results. It consults its own magnetic memory for permissible deviations from the normal response. In this way it decides whether the circuits involved are "normal" or "sick."

Automatic checkout in orbit, too

Modern automatic checkout systems can handle vast quantities of such checking operations in a short time. Since digital techniques are used throughout, all signals flowing back and forth between the ground-based checkout installation and the space vehicle consist of rapid-fire bursts of simple electrical impulses.

This makes it relatively easy to run an automatic checkout, over a radio link, even after launch and while a rocket is in flight.

In the Saturn/Apollo lunar-landing program it is definitely planned to check out the third stage of the Saturn V once more after it has been injected into its parking orbit. We want to make sure in this way that everything is still shipshape, before the astronauts restart this stage and continue their voyage to the moon. ■ ■

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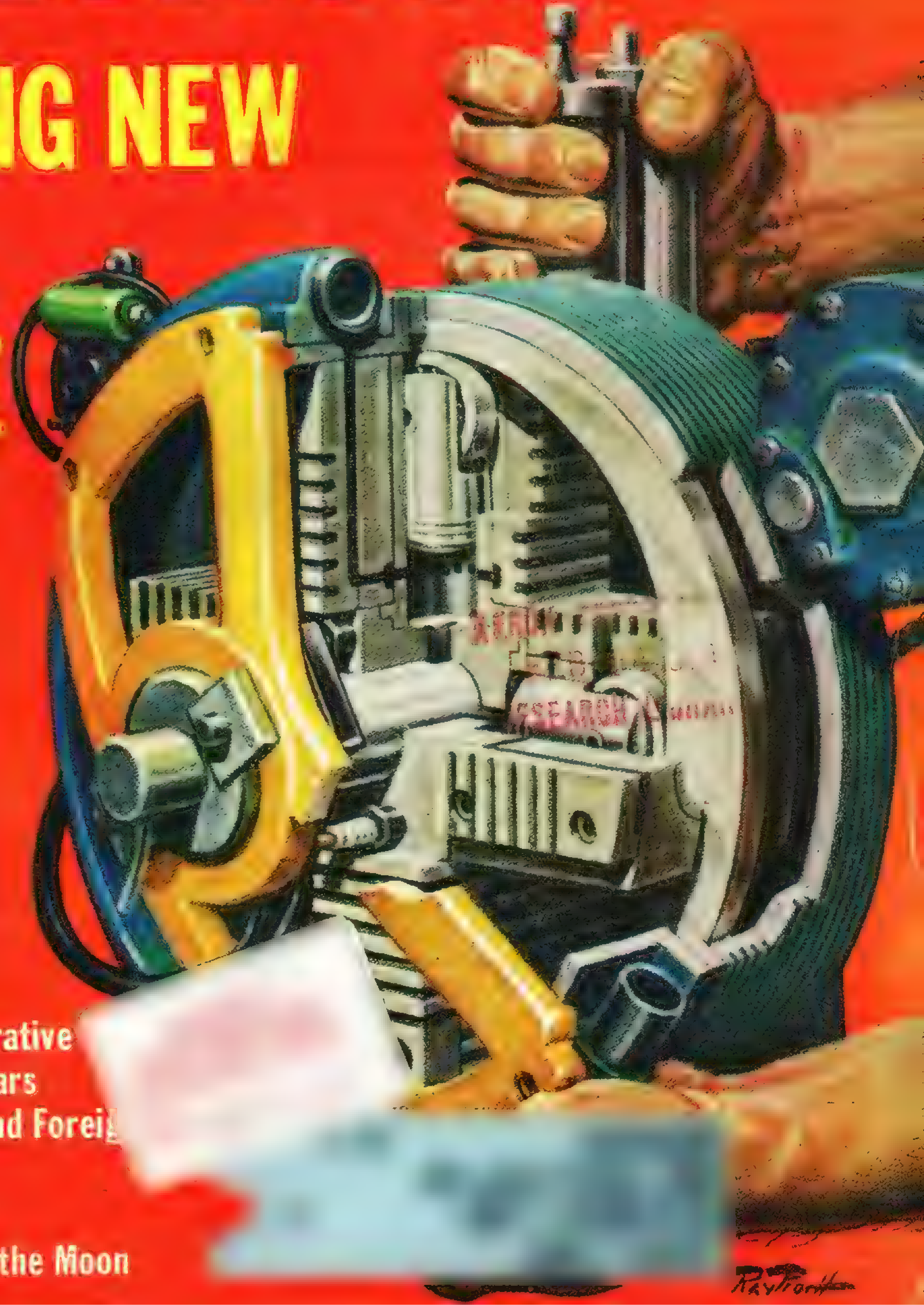

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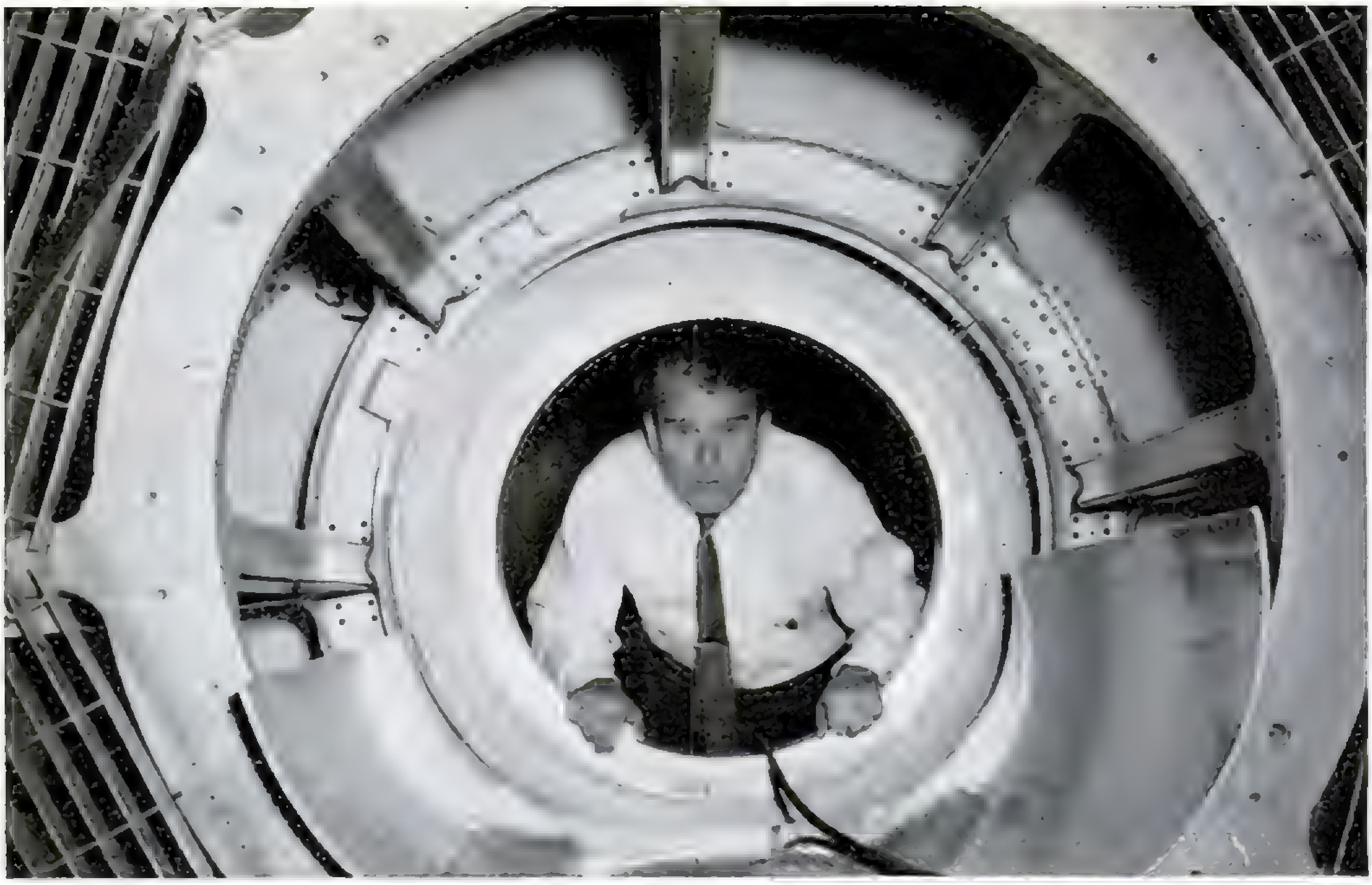
Dr. von Braun Tells How We'll Travel on the Moon



Dr. von Braun inspects Saturn I rocket's second stage at Douglas test facility in Sacramento.

Dr. Wernher von Braun tells
How We'll Travel on the Moon

Q *What will vehicles for traveling on the moon be like?*

A There will be several types, for several different applications.

Even before the first astronauts set foot on the moon, a small, fully automatic roving vehicle may have explored the immediate vicinity of the landing site of its unmanned carrier spacecraft. Remotely controlled by an armchair driver back on earth, who sees the lunar landscape roll past on a television screen as though he were looking through a car's windshield, such an automatic vehicle could furnish valuable information on the makeup of the moon's surface.

The initial manned lunar-landing attempt will undoubtedly involve so many pioneering firsts that the exploratory tasks to be performed by the astronauts on the lunar surface will be severely limited, simply to assure maximum chances of success. But to exploit fully the scientific possibilities opened by the spectacular first touchdown, subsequent landings will require two elements of support:

First, lunar shelters will be needed, where the astronauts can get out of their space suits and rest.

Second, we must provide adequate ground transportation. The visible part of the moon extends over an area twice the size of the United States—and the far side of the moon is just as large.

For short-distance travel a nonpressurized "moon jeep" may suffice. The astronauts would hop onto its open platform and depend for protection upon their pressurized space suits, while life support and communication would be provided by their back packs.

Longer surface journeys will require a pressurized vehicle that offers air-conditioned comfort in a "shirtsleeve" environment, and room for the explorers to stretch out during rest periods. An airlock will be

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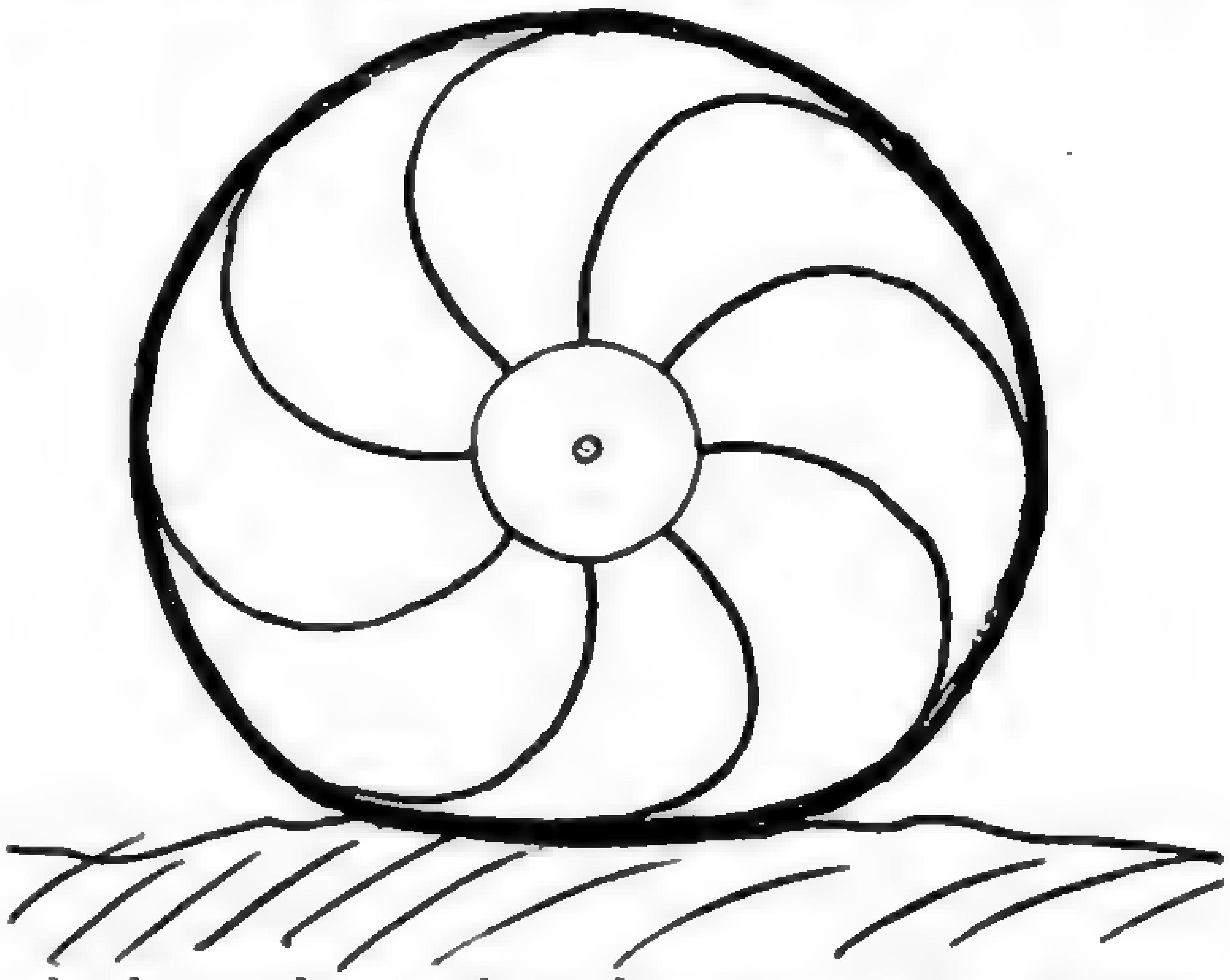
needed, to get in and out. The vehicle must be equipped with a two-way radio. And there must be ample facilities for research tasks en route.

Wheels or Tracks?

As there are no superhighways on the moon (yet), all vehicles must have cross-country capability. Just as on earth, the terrain on the moon is partly smooth and flat, while other parts are rugged and mountainous. It would be unrealistic to demand a lunar vehicle that could negotiate any and all surface conditions. Rather, we must rely on moon-circling photo satellites to scout for suitable access routes to lofty crater rims and other interesting objectives for surface expeditions. An ability to negotiate a slope of 15 to 20 degrees appears adequate for even the most demanding missions.

Caterpillar treads provide more traction than wheels, but at a cost of greatly increased horsepower. This, whatever power source we use, means more weight. And weight is a precious commodity on the moon, where every ounce will have to be shipped from earth—until we can produce our own fuel there, as some day we undoubtedly will.

Careful analyses show that under the "unearthly" conditions of the moon—where a 170-pound man weighs only 29 pounds—the wheel seems to have a decided edge over the endless track. A particularly intriguing concept for lunar surface vehicles is a wheel with elastic spokes (see my sketch below),



which combines the advantages of a smooth ride with an enlarged traction area. For

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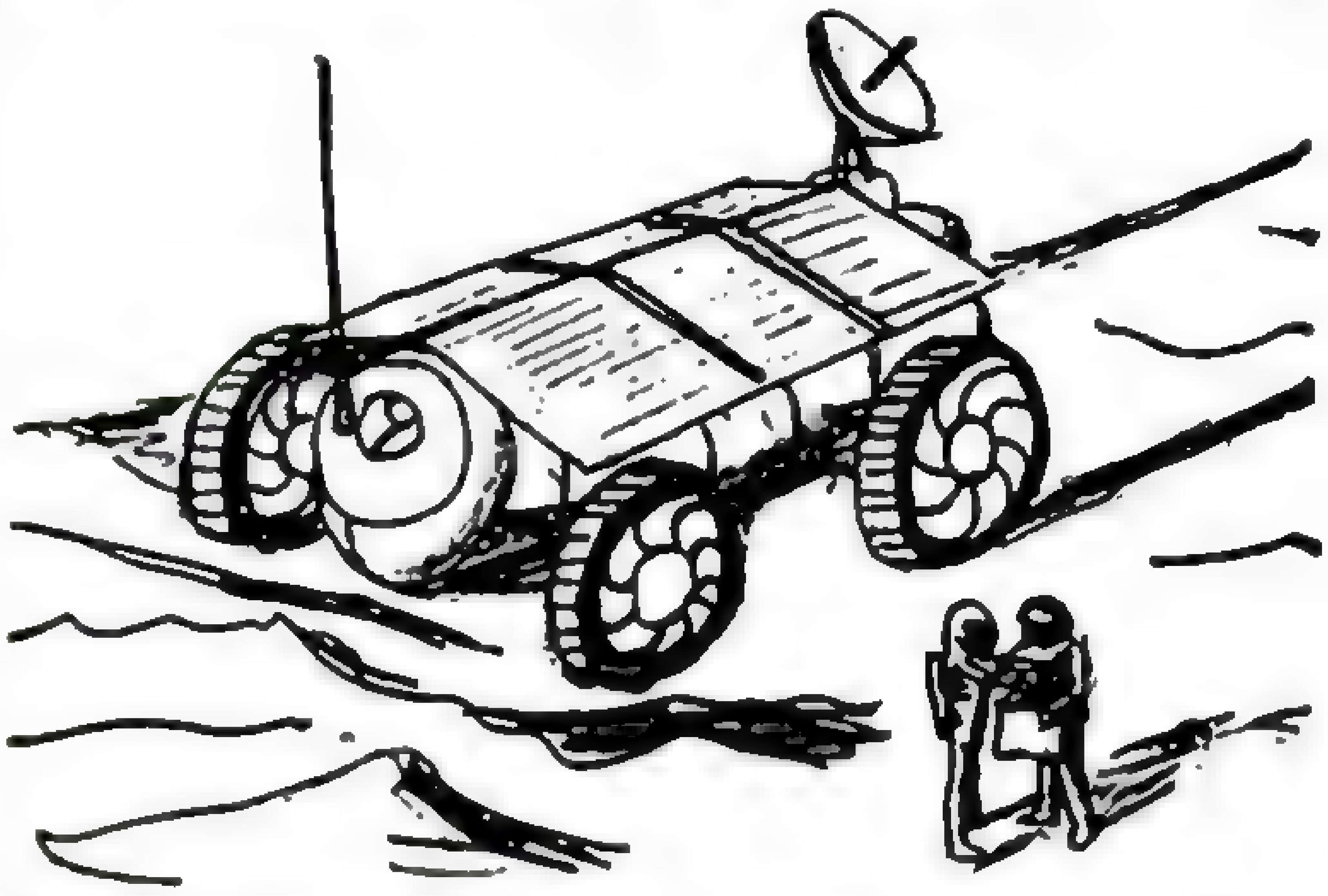
extra traction in soft terrain, lugs may be attached to the flexible wheel rims (or extended by pushbutton action), just as you would put snow chains on your tires.

To avoid bogging down in soft ground, the wheels must be large in diameter. By



Detroit standards this will give moon cars a rather weird appearance (see my second sketch, above).

Power for Lunar Vehicles

As the moon has no atmosphere, conventional combustion engines are out. Solar batteries, such as power the instruments and radios of most of our unmanned satellites and deep-space probes, may at first blush look like an obvious source of cheap power on the cloudless moon. But they need about 25 square yards of area to produce one puny horsepower, and so a rather large energy-collecting "sail" would be required. While this is fine for a stationary power plant, it is not too compatible with the bumpy ride of a cross-country vehicle moving over rugged terrain. Moreover, solar batteries are ineffective during the lunar night—which, particularly during periods of bright "earthshine," may be a very attractive time for surface travel.

Nuclear power sources for vehicular application entail nasty radiation problems and do not look too attractive at this time.

Among the best bets seems to be the hydrogen-oxygen fuel cell. Remember the old physics-lab experiment demonstrating "electrolysis"? An electric current is sent through a tray of water, and the current breaks up ("dissociates") the water molecules, with the result that hydrogen gas bubbles up at one electrode and oxygen gas at the other. In a fuel cell the process is just the other way around: Hydrogen gas

CONTINUED

and oxygen gas are fed into the cell, and out comes an electric current. The efficiency of the process is about 60 percent, which is better than that of our finest turbogenerators. (This is why industry has high expectations for the extended use of fuel cells in commercial power generation—another example of an invaluable "fallout" product of our space program.)

An expert looks at moon cars

Earlier articles in this magazine have pictured a wide variety of rolling, walking, and crawling vehicles envisioned as possible designs for travel on the moon [PS, Mar. '62; May '63; Jan. '64].

Now, Dr. von Braun explains here the underlying considerations that will govern the choice of a practical "moon car" from among the many designs proposed. Already, he points out, reasonably likely forecasts can be made about such things as the kind of power plant and method of locomotion that a lunar surface vehicle will use.—THE EDITOR.

Fuel-cell power for lunar surface vehicles looks very attractive even for early applications, where the hydrogen and oxygen propellants must still be flown in from earth. At a later stage of lunar surface exploration, once we have a nuclear-power reactor on the moon (such as NASA's Snap 8 or Snap 50), we can easily produce hydrogen and oxygen from a lunar research station's waste water—or even from the "crystal water" that geologists believe can be extracted from lunar minerals.

Engineering Problems to Be Solved

Each wheel of the lunar surface vehicle would be powered by one or more electric motors, driven by current from the fuel cell. But since there is no atmosphere on the moon, we cannot air-cool these motors. This presents a serious problem, particularly for travel during a hot lunar day, when surface temperatures climb beyond 200 degrees F. The best solution seems to be to use ceramic insulating materials that will permit the motors to operate at temperatures of 400 to 500 degrees, where heat radiation will provide for cooling.

Lubrication poses another problem. Liq-

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uid lubricants (such as oil or grease) rapidly evaporate from bearings exposed to the hard vacuum of outer space. Dry lubricants (such as graphite or molybdenum sulfide) are not nearly as effective in a vacuum as in the atmosphere—where an air film gets between journal and bearing. Sealed, pressurized bearings are a possibility, but they are complex and troublesome. It is probably fair to say that while we have enough know-how to build adequately lubricated bearings for lunar surface vehicles of limited lifetime, there is much room for improvement and advanced concepts in this field.

Day and Night Air Conditioning

Temperature control for the living and equipment spaces aboard a lunar surface vehicle suitable for long-distance operations poses another difficulty. Such a vehicle should be capable of day and night travel. During the 14-day lunar night we have no problem—as in an automobile, we can always tap a little power for heating, and it is easy to provide effective heat insulation. Cooling, wherever necessary, is just as easy, because the excess heat can be radiated out against the "heat sink" of the cold lunar surface (−240 degrees F.) and the even colder star-studded universe above it. But during the lunar day the moon's surface is blazing hot, far hotter than the 72-degree F. comfort temperature we propose to maintain in the vehicle.

The best answer seems to be a well-insulated vehicle, painted white or silver—to minimize its heating by radiation from the lunar surface—and equipped with an air-conditioning system that permits radiating the excess energy away at a temperature level elevated to several hundred degrees. The hot "heat-rejection surfaces" must be located on the vehicle's top, or possibly (if the vehicle is to descend deep into brightly sunlit lunar canyons) on parabolic dishes, which can be aimed like a radar antenna at a stretch of cold sky overhead. ■■

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Dr. Wernher von Braun tells why

We Need to Know More About the Sun

Dr. von Braun examines a model of the Saturn rocket that will orbit an early Apollo spacecraft around the earth.

Q ***Why are scientists so interested in the sun?***

A It is virtually the mainspring of life on earth. Not only does the sun furnish the necessary warmth to sustain life—without sunlight, there could be no photosynthesis, the basic process that enables plants to grow. And without plant life, there could be no animal or human life.

For many scientists the sun has another significance: It is the nearest of the billions of fixed stars—and therefore the one best suited for close scrutiny. By observing the sun, we may learn more of the physical phenomena at work throughout the universe.

To be sure, there are many kinds of fixed stars. The sun (a rather common type, class G) cannot furnish all the answers we seek. But it has already taught us much about the cradle-to-grave cycle that all stars seem to go through.

With our first Orbiting Solar Observatory successfully launched, and ever more elaborate ones on the way, we are hampered no longer by the "dirty basement window" of our atmosphere—and are bound to extend our knowledge of the sun vastly.

Q ***Is the sun solid, liquid, or a ball of gas?***

A We have direct evidence that the visible surface of the sun could not possibly be solid: The sun rotates on its axis in roughly four weeks; but, while the equator takes about 25 days, the polar regions take 31 days. Actually the sun's surface temperature of 11,000 degrees F. makes it obvious that the sun must at least be enveloped in a layer of incandescent gas.

While this would not preclude the possibility that the invisible interior might be liquid or solid, there is other strong evidence to the contrary—the enormous amount of energy that the sun radiates continuously. Its calculable rate is such that the sun's gaseous outer surface would have cooled off noticeably in just the last few hundred years, if its temperature had not been kept up by an even hotter interior. So the sun's temperature must further increase as we descend from the surface toward the center.

This means, of course, that the sun must be a sphere of gas throughout—even if its central portion contains elements heavier than the hydrogen that predominates at the surface. Furthermore, there must be some mechanism to replenish those enormous energy losses.

Q ***What keeps the sun hot?***

A It is now believed that the inner region of the sun (up to about 23 percent of the sun's radius) forms a huge thermonuclear reactor, where hydrogen is transformed into helium.

The temperature in the central nuclear-reaction zone is estimated at about 25,000,-

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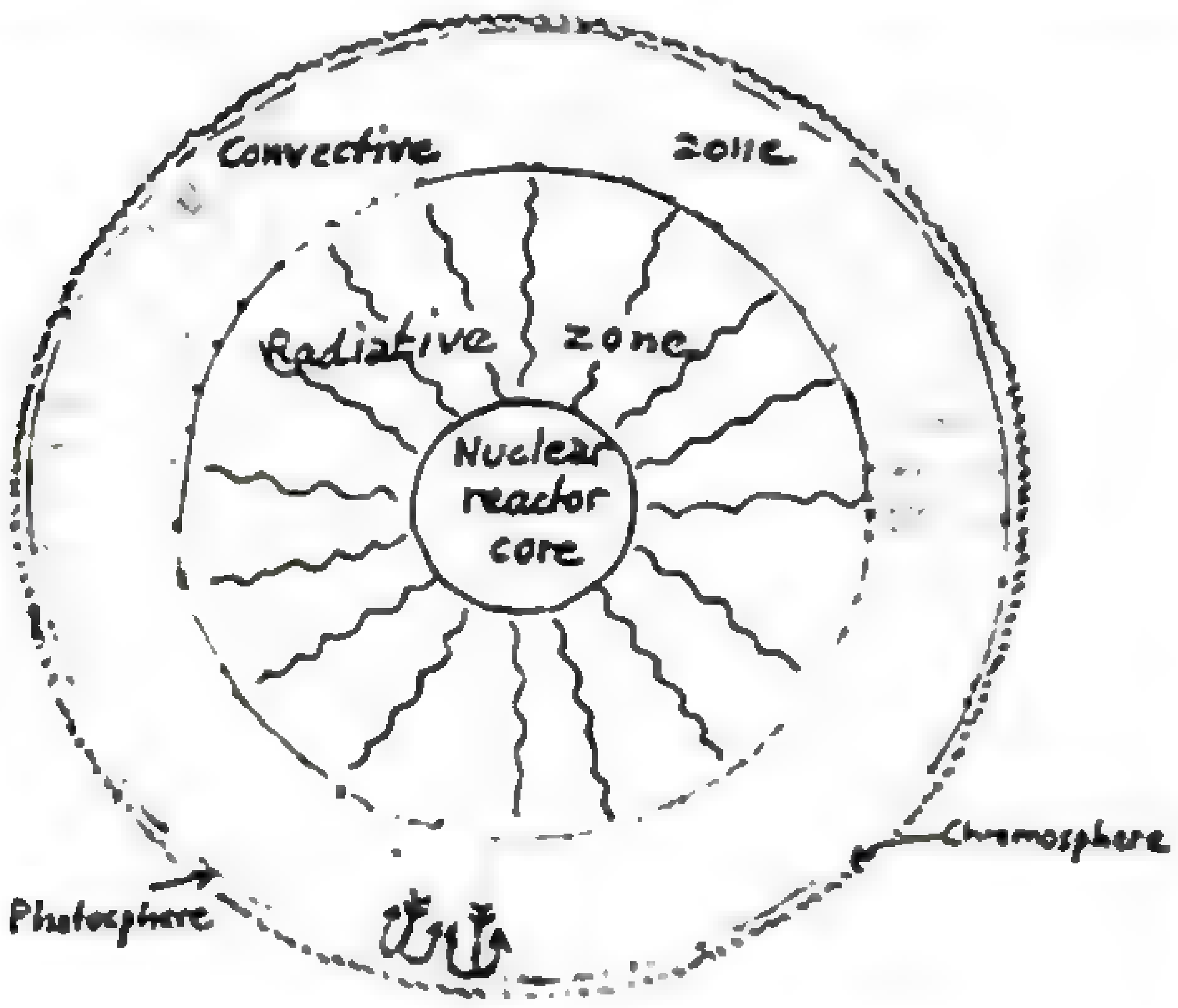
000 degrees F. Yet the pressure is so high, because of the sun's enormous gravitational field, that hydrogen gas (which makes up the bulk of the sun's mass) weighs about 100 times as much as water. Under these conditions the atoms are tightly spaced, whirl at tremendous speeds, and collide often and vehemently enough to undergo "thermonuclear fusion" into helium atoms.



Cross section through sun.

Such a fusion is accompanied by the release of a huge amount of energy.

This "hydrogen burning" is *not* a chain reaction. The thermonuclear reactor in the sun is kept going simply by the extreme conditions of pressure and temperature.

Any star, in a way depending directly on its total mass, establishes its own equilibrium between gravitational field, nuclear-core temperature, resulting energy release, and surface temperature. As a general rule, a star's surface temperature increases with its size. And so does its "luminosity," the absolute light energy emitted by a star, regardless of its distance from the earth.

Q ***How does the heat of the sun's nuclear core reach the surface?***

A Within the core and the area around it, the energy is radiated outward—in the form of X rays and gamma rays. Heat transfer by *radiation* is so dominant in this region, where temperatures exceed 1,000,000 degrees F., that convection can be disregarded.

At about 70 percent of the distance from center to surface, the temperature has

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dropped to about 250,000 degrees F.; and the gas density to less than 1/10 of that of water. Under these conditions, radiation no longer can maintain the outward flow of energy, and *convection* now takes over the major role. Energy is carried by the buoyant upward motion of heated material, through a steep temperature gradient, somewhat like a cumulus cloud that is bursting into the colder upper atmosphere. Heated material that has already reached the surface, and has cooled off by radiating its energy away, descends back to the radiation zone through the spaces left between the billowing cumulus towers.

The top of this convection zone is the source of all visible sunlight. Magnified solar photographs clearly show the granular structure of the rising cumulus-like formations. Astrophysicists call this region the *photosphere.* It has a temperature of about 9,000 degrees F.

Immediately above lies the *chromosphere,* a turbulent layer of gases about 6,000 miles high, with a density of less than 1/1,000 as much as the photosphere. It is a seething mass of gaseous fountains heated to about 11,000 degrees F. It has been called the "spray" of the photosphere because it is kept in continuous motion by the heaving photosphere beneath.

Constant kicks by the fast-rising cumulus towers below send supersonic shock waves traveling across the chromosphere. These waves, dissipated in the chromosphere, account for its somewhat higher temperature. If we could lower a heat-resistant microphone into the chromosphere, it would undoubtedly transmit a continuous roar of thunder. Despite the higher temperature, the chromosphere emits far less radiation than the photosphere, because of its lower gas density.

Q ***What is the corona?***

A It is a huge layer of rarefied gas surrounding the sun and extending out to one or two solar diameters, with conspicuous streamers sometimes reaching far beyond. We see it during total eclipses, when the moon hides the sun from view. The corona's shape is greatly affected by the number of sunspots present.

CONTINUED

The corona is only about 1/1,000 as dense as the chromosphere, but its temperature is of the order of 2,000,000 degrees F. Just as the photosphere heats the chromosphere by thrusting up its granules, so the chromosphere heats up the corona with supersonic gas bursts. The higher temperature in the corona is again accounted for by energy-dissipation of shock waves.

Q *How about sunspots?*

A It is now generally accepted that a sunspot is formed whenever a strong local magnetic field arrests one or more of those rising cumulus granules in the sun's convective zone.

Once their convective movement is braked, local heat transport stops. The affected area cools down through radiation losses—and becomes a dark sunspot.

How do we know this? What is probably the most direct proof lies in the so-called Zeeman effect in the spectrum of the area around a sunspot. Seventy years ago the physicist Zeeman discovered that each of the spectral lines in the light emanating from a luminous gas (for instance, from a neon tube) split into two or three lines as soon as the gas was placed in a magnetic field. The spectral lines of light from the vicinity of a sunspot do just that. Magnetic-field strengths up to 3,000 gauss have been measured around some big sunspots. This is quite a bit when we consider that the earth's magnetic field, which turns our compass needles, has a strength of only a fraction of one gauss.

The hot "cumulus" gases, heaving up at supersonic speeds through the sun's convective zone, are highly ionized or stripped of most of their electrons. Thus they are very good electrical conductors. As the surrounding magnetic field induces a current in the rising gas column, the latter is braked to a halt, just like a copper disk rotating in a magnetic field. ■■

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Dr. Wernher von Braun tells About Comets and Meteors

Dr. von Braun (on speaker's stand, left) accepts first Chrysler-built Saturn rocket from firm's president Lynn Townsend (beside him) at NASA's Michoud plant in New Orleans, La.

Q ***What is a comet?***

A It is a relatively small body moving in a closed orbit about the sun. The eccentric shape of its orbit and, of course, its tail, set a comet apart from a planet or an asteroid.

Comets so bright as to outshine all but the sun and moon may appear once or twice in a century. Others, fainter but visible to the naked eye, occur every few years. There are always a few comets in the sky that can be seen or photographed with powerful telescopes.

A comet has three visible parts. Its head, called the coma, forms a bright diffuse cloud. Within is a solid starlike nucleus, 1 to 50 miles in diameter. The tail, a comet's most conspicuous feature, looks like a stream of gas, always pointing away from the sun.

Near the aphelion—the point farthest from the sun in a comet's highly elliptical orbit—its nucleus is dim; there is hardly any coma, and never a tail. Only as the comet swings nearer the sun do things begin to happen. (See my diagram at the top of the next page.)

First the solid nucleus surrounds itself with the nebulous coma. Then the tail develops. The comet becomes brightest and in fullest bloom near the perihelion, its closest approach to the sun. Unfortunately, it cannot then be observed too well from the earth's surface, because the bright dawn or dusk sky interferes with the observation of an object so near the sun. Orbiting telescopes offer a promising answer.

Photographic and spectrographic studies have led Prof. Fred L. Whipple, head of Harvard Observatory, to propose a comet "model" that has found almost universal acceptance, and that explains nearly all observed cometary phenomena.

The nucleus from which coma and tail arise, he suggests, consists of porous rock froth, impregnated with frozen water, ammonia, methane, and carbon dioxide. Far from the sun, this conglomeration is cold and dormant. But as the comet nears the sun, solar heat begins to vaporize the frozen gases. Some of this vapor forms the nebulous coma; the rest forms the tail, which is blown away from the comet by some repulsive force

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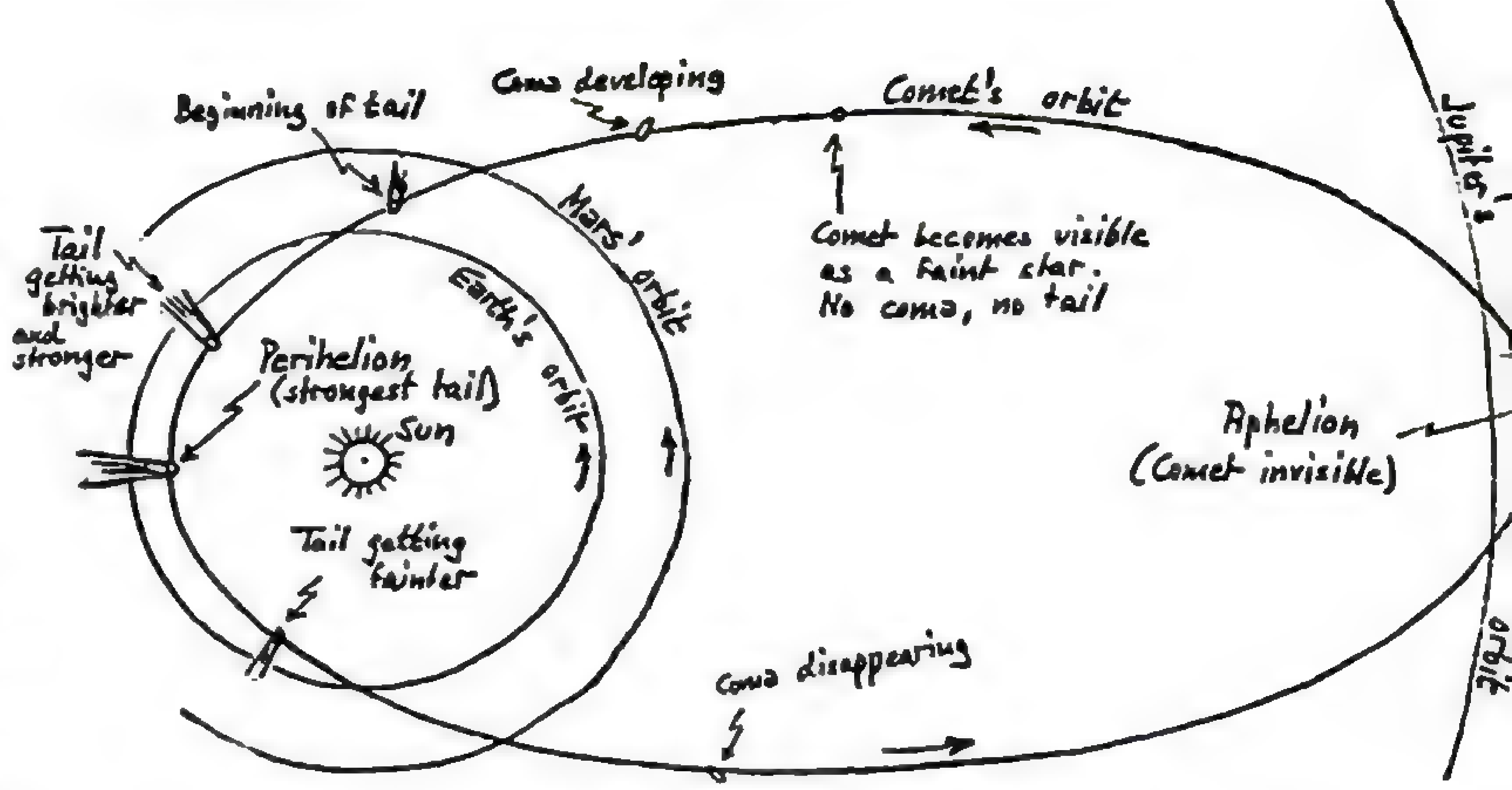
centered at the sun. One such force might be light pressure, exerted on matter by impacting photons. But this tiny force cannot explain all we observe:



First, the tremendously long straight streamers of some comets' tails could be caused only by a repulsive force many times stronger than light pressure. Second, some tails are curved, or have straight and curved portions. (See my sketch below.) Third, all comets' tails are two-dimensional, being confined to the plane of the comet's orbit. This becomes dramatically apparent when the earth happens to pass through that plane: The tail abruptly disappears. It is as if a flat picture of it were turned edgewise to your eye.

To these puzzles, spectral analysis provides a clue: The extremely tenuous gases of a comet's tail are almost completely ionized, or electrically charged. This makes them susceptible to attraction or repulsion by electrostatic and magnetic fields.

Now, the sun emits great streams of electrons and protons during rather frequent solar eruptions. As these electrostatically charged particles traverse space, they carry with them vast magnetic fields—and comets are bound to run into them. Thus, the varied forms of comets' tails result not only from solar light pressure, but also from electrostatic and magnetic forces acting upon the ionized gases that comets' tails are made of.

Q ***Since a comet gives off matter, how long does it live?***

A That depends primarily on how fast it loses mass by evaporation—which, in turn, depends on how close it comes to the sun during perihelion passes. So its life is determined by its orbit.

Astronomers divide comets into a short-period group, taking less than 200 years to complete their orbits; and a long-period group, taking more. Short-period comets seem to prefer orbits in or near the ecliptic, the plane in which the earth circles the sun. Long-period comets' orbital planes vary at random—and the lifetime of these comets is unknown, for the science of systematic comet observation is not yet even 200 years old.

Jupiter, largest planet in our solar system, has a great effect on comets' orbits. Whenever a comet happens to pass near Jupiter, the planet's powerful gravitational pull will throw it off its path. Sometimes this increases the aphelion, the maximum orbital distance from the sun—and occasionally may even result in an escape trajectory taking the comet right out of the solar system. The most likely effect, though, seems to be a decrease of the comet's aphelion distance, for about half of all short-period comets have an aphelion close to Jupiter's orbit. The orbital period of comets like these is less than 10 years.

Just as Jupiter's pull tampers with a comet's aphelion distance, it can reduce the perihelion distance—to the point where the comet may plummet smack

into the sun, and be consumed forever.

If the comet just grazes the sun, solar heating may still be so great that all frozen gases evaporate completely and are blown away in a gigantic tail. Even a good part of a comet's solid nucleus may also be vaporized.

A fly-by at somewhat greater distance may still result in solar tidal forces that rip a comet apart. Fragments of its solid nucleus will then enter the outbound part of the original orbit at slightly different speeds, which leads to slight differences in their orbital periods. Thus, after a number of revolutions, the material of the original nucleus becomes scattered all over the orbit. When the earth crosses the orbit of such a comet, we witness a meteor shower.

From Explorer to Saturn

(Excerpts from *Aviation Week* editorial)

"The flawless performance of the two-stage Saturn SA-5 launch vehicle [Jan. 30] marks the end of the long stern chase with the Soviet Union in the key categories of booster thrust and orbital payload.

"The 37,700-lb. weight hurled into orbit by SA-5 was more than 1,000 times heavier than the first successful U. S. satellite, Explorer 1, which was launched just six years earlier. Two veterans of the Explorer 1 launch—Dr. Wernher von Braun, director of the Marshall Space Flight Center, and Dr. Kurt Debus, director of the Kennedy Space Center—played key roles in the SA-5 launch.

"The clustered engine concept was developed by the Army's Redstone Arsenal group headed by Dr. von Braun under the sponsorship of the Advanced Research Projects Agency. We recall vividly the technical catcalls about 'Wernher von Cluster' and the dire predictions of disastrous pyrotechnics when NASA would be foolish enough to actually try to launch SA-1. The flawless record of five perfectly executed Saturn launches confirmed the technical vision of the von Braun group."

Q ***What are meteoroids, meteors, and meteorites?***

A A meteoroid is an individual chunk of matter traveling through outer space. It may have a size anywhere from a dust speck to a block weighing several tons.

A meteor is a meteoroid that enters the earth's atmosphere. Heated by air friction, it causes the streak of light we see as a shooting star. Very bright meteors are often called fireballs.

A meteorite is an unconsumed portion of a meteoroid that reaches the ground.

Don't be too surprised, though, if you sometimes find these terms used with their meanings interchanged.

The speed at which a meteoroid may enter the atmosphere and become a meteor ranges from about 7 to 45 miles a second. The lower limit is set by the speed of a body falling from infinite distance under the pull of the earth's gravity; the upper limit, by the combined speed produced by the sun's gravity and the earth's velocity in its orbit.

Meteorites found on earth must be distinguished as of "stone," "iron," and "intermediate" types. The relative abundance of these three kinds on earth does not necessarily prove, however, that the same ratio applies to pre-atmospheric meteoroids. Actually, there is evidence that a great many meteoroids break up in the atmosphere at relatively low dynamic pressures, showing their extreme fragility. Sizable pieces of such fragile meteoroids are much less likely to reach the ground than rugged chunks of stone or iron.

This has particular interest in connection with meteor showers—which, we have seen, occur whenever the earth crosses the orbit of a comet that has slowly disintegrated under solar heat and tidal effects. According to Whipple's "model," all that remains of its solid nucleus is highly porous material—and this could be expected to be fragile. So we may conclude that few if any of the meteorites we find on the ground are of cometary origin.

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Astronauts Will Land Standing Up

Dr. von Braun (right, in photo) confers with Donald W. Douglas Jr., president of Douglas Aircraft, at Cape Kennedy before start of count-down for launching the Saturn I rocket seen in background.

THE latest design for Project Apollo's moon-landing spacecraft eliminates seats for the occupants. Instead, the two astronauts will stand up suspended by straps, parachute-harness fashion, when their vehicle touches down—and when it takes off again. A news item to this effect prompted a PS reader to ask Dr. von Braun:

Q ***I've heard that the first U.S. astronauts to land on the moon will be "straphangers." Why is this?***

A It gives them better vision and more freedom of action, and it saves weight.

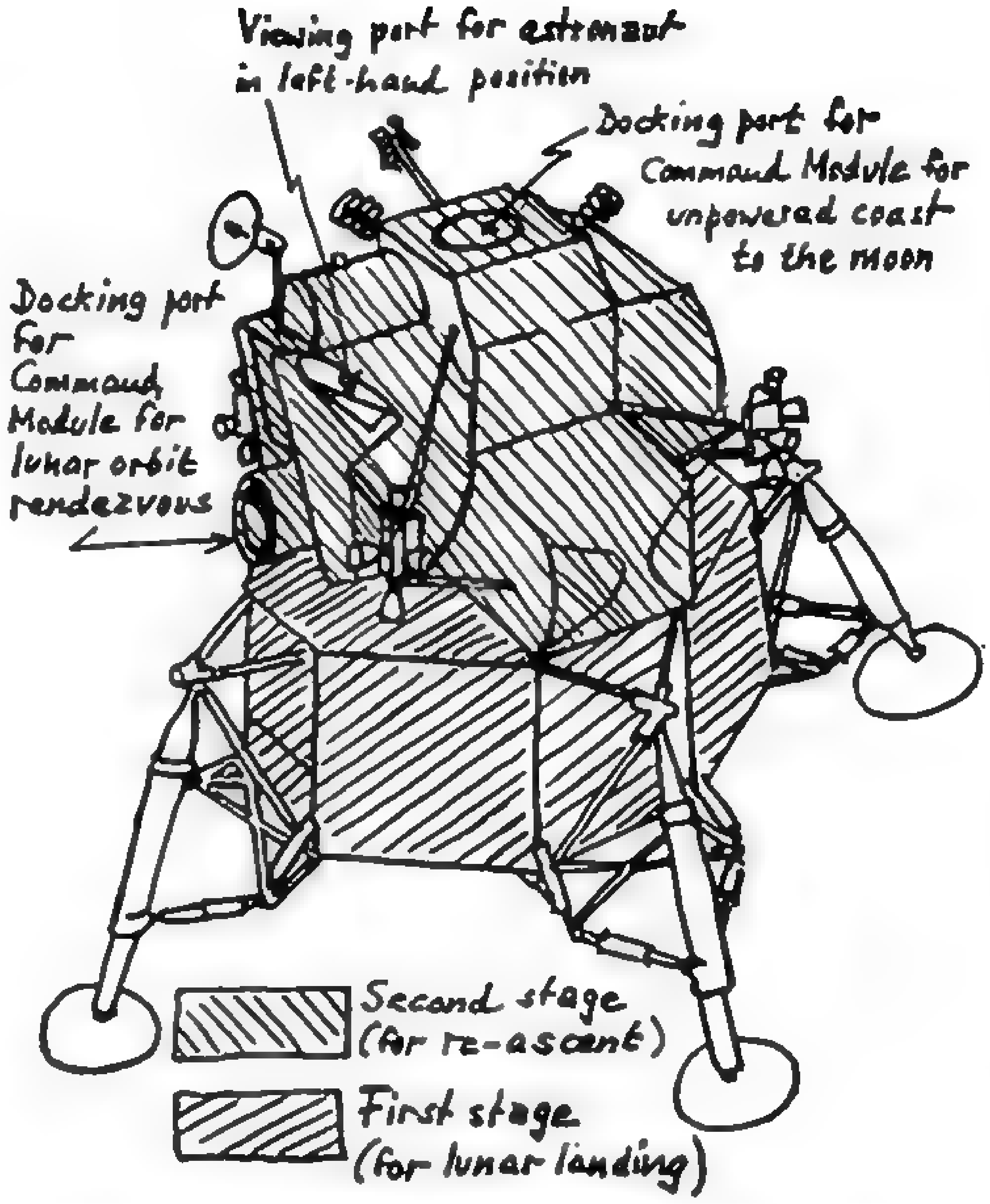
In Project Apollo, our national lunar-landing program, the actual touchdown on the moon will be performed with a separate vehicle called the Lunar Excursion Module, or LEM. (See my sketch on the facing page.) This two-stage, rocket-powered vehicle, with two astronauts aboard, will detach itself from its mother ship, the combined Command and Service Module (CSM)—which remains in orbit around the moon with a third astronaut as "shipkeeper."

The LEM slows down from initial circumlunar-orbit speed and touches down under the power of the throttleable rocket engine of its landing stage.

The return flight to the circumlunar orbit, and the rendezvous maneuver with the CSM, are performed with the second stage of the LEM. This stage has its own rocket engine and propellant tanks, and uses the burned-out first stage as its launch platform on the moon.

The astronauts' compartment forms part of the second or upper stage—which, during the let-down maneuver, consti-

tutes the payload for the first or landing stage.



Q ***How will they see out?***

A In principle it would be possible, of course, to provide the urgently needed good vision for the two landing astronauts by fashioning the LEM's crew compartment like the Plexiglas bubble cockpit of a small helicopter. However, such a solution would have a number of drawbacks.

For one, there is not room enough for a picture window. The flight deck of the LEM is plastered with more instrumentation and displays than that of a large airliner. This is easy to understand. Not only must it provide for flight control of two independent LEM stages; the astronauts must also be able to perform quite a number of different tasks besides the critical maneuvers of touchdown on the lunar surface and rendezvous in lunar orbit with the CSM.

Q ***What else will they be doing?***

A They must, for example, be able to monitor their life-support systems continuously. Should the landing area prove unsuited, they must be in a position to conduct a "landing abort" maneuver, with immediately ensuing return to lunar orbit and rendezvous with the CSM. They must communicate with the CSM and with the earth. They must be able to perform whatever navigation is necessary to correct for errors that may have made a rendezvous attempt unsuccessful at first try. The LEM is equipped for all this and, in addition, with a complete inertial-guidance system of its own.

Then, too, a bubble-type compartment costs quite a bit of weight. For, unlike the cockpit of a helicopter, the LEM must be pressurized.

Finally, for the touchdown on the lunar surface, the astronauts must have a good view down. They are interested in avoiding local obstacles, and they also would like to observe whether the surface of their selected landing spot has sufficient bearing strength to support the forward leg of their landing gear as it touches the ground. (If it doesn't, they can gun their landing engine and try to find a better spot nearby.) In addition to providing a good view downward, the windows must offer a good view *forward* for the equally critical maneuver of rendezvous and docking with the CSM, at the end of their landing excursion.

Another factor: The astronauts already are somewhat hampered in their freedom of action and field of view by their space suits and helmets.

All these considerations have led to adoption of a concept whereby the two LEM astronauts will assume a standing position throughout all phases of the LEM flight.

Q ***Where does the straphanging come in?***

A They will be supported by parachute-type harnesses attached to straps hung from the ceiling (see my second sketch farther on). This arrangement enables the astronauts to conveniently reach the many switches and view

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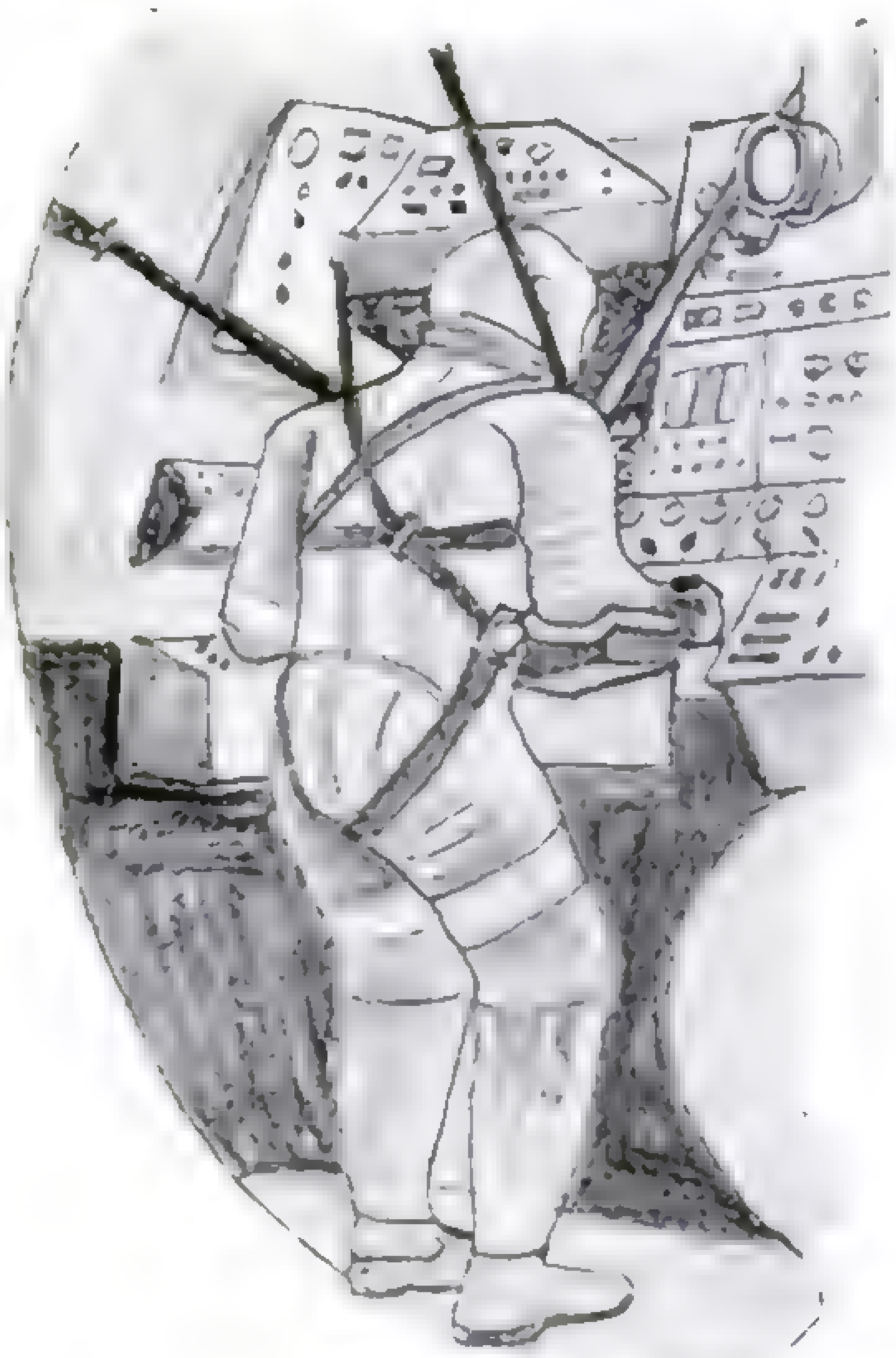
all the many dials within the LEM crew compartment. Moreover, they can virtually press their noses against the relatively small windows, for a perfect wide-vision view outside.



Even for a helicopter landing on earth, there would be nothing wrong with a standing position for any of the crew members. In the LEM, there is still less restriction upon choice of posture. The moon has only one-sixth of the earth's gravity—so, throughout the descent and ascent maneuvers, the accelerations within the LEM will never exceed one G. In case of an exceedingly rough touchdown on the moon, a well-designed suspension system may even be safer than a conventional pilot's seat because of the longer travel available for the shock absorbers built into the suspension straps.

Weight-Saving an Advantage

The resulting weight-saving is important, too. Every pound of LEM, carried all the way to the lunar surface and back to the lunar-orbit rendezvous, is heavily mortgaged with more than 100 pounds of original departure weight from the earth's surface. The adoption of the "straphanger" concept substantially reduces the LEM's weight by decreasing the size of windows for the pressurized cabin—and, of course, by omitting the heavy seats themselves.

CONTINUED

Q *What is "albedo"?*

A Albedo is an astronomical term for the fraction of the total sunlight striking a planet, or the moon, that is reflected back in all directions.

By definition, a perfectly diffusing (dull-white) surface has an albedo of one. All actual surfaces have albedos less than unity. The moon, reflecting only seven percent of the total sunlight it receives, has a rather dark surface; its albedo is 0.07.

Mars has an albedo of 0.15. This higher value is due partly to Mars' blinding-white polar caps. Venus' enormous albedo of 0.76 is accounted for by the permanent veil of cloud surrounding the planet. The earth has an albedo of 0.39, about what one would expect for a planet only partly covered with clouds.

The earth's albedo enters into space flight because it greatly affects the temperature equilibrium of a spacecraft orbiting the earth at low altitude.

An orbiting Mercury capsule, for example, absorbed external heat from:

- Direct sunlight.
- Infrared radiation, caused by the earth's own moderate warmth.
- Sunlight reflected by the earth's surface, or clouds, or both. Here is where the albedo comes in.

As each of our Mercury astronauts orbited from the earth's day side into the night side, the sun would first set on the earth beneath him, cutting off the *reflected* sunlight. Shortly after, the sun would sink beneath the horizon, shutting off the *direct* sunlight, too. During the 40-odd minutes of his flight through the earth's shadow, the only heat absorbed by his capsule was *infrared radiation* from the earth. As he passed back into the sunlight again, first the direct sunlight and then, a minute or so later, the reflected sunlight helped warm his capsule once more.

So, in calculating the household temperature of an orbiting satellite, the albedo is of great importance. ■ ■

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Wernher von Braun: Will Astronauts Pilot Rocket Boosters?

Dr. Wernher von Braun:

Will Astronauts "Fly" Rocket Boosters?

Q ***Can rocket boosters be flown by manual control?***

A There is really no obvious reason why they cannot.

Of course the stringent accuracy requirements of orbital and other space missions make it mandatory that the rocket follow a precisely planned trajectory.

Currently it is led along this path by radio guidance or by inertial guidance. In either case, two signals are produced aboard the rocket. One says "up" or "down"; the other, "left" or "right." In all space rockets flown so far, whether manned or unmanned, these two guidance signals have been wired directly into the autopilot. Through deflection of jet vanes, rocket nozzles, or entire rocket engines, the autopilot has then actually controlled the rocket's flight.

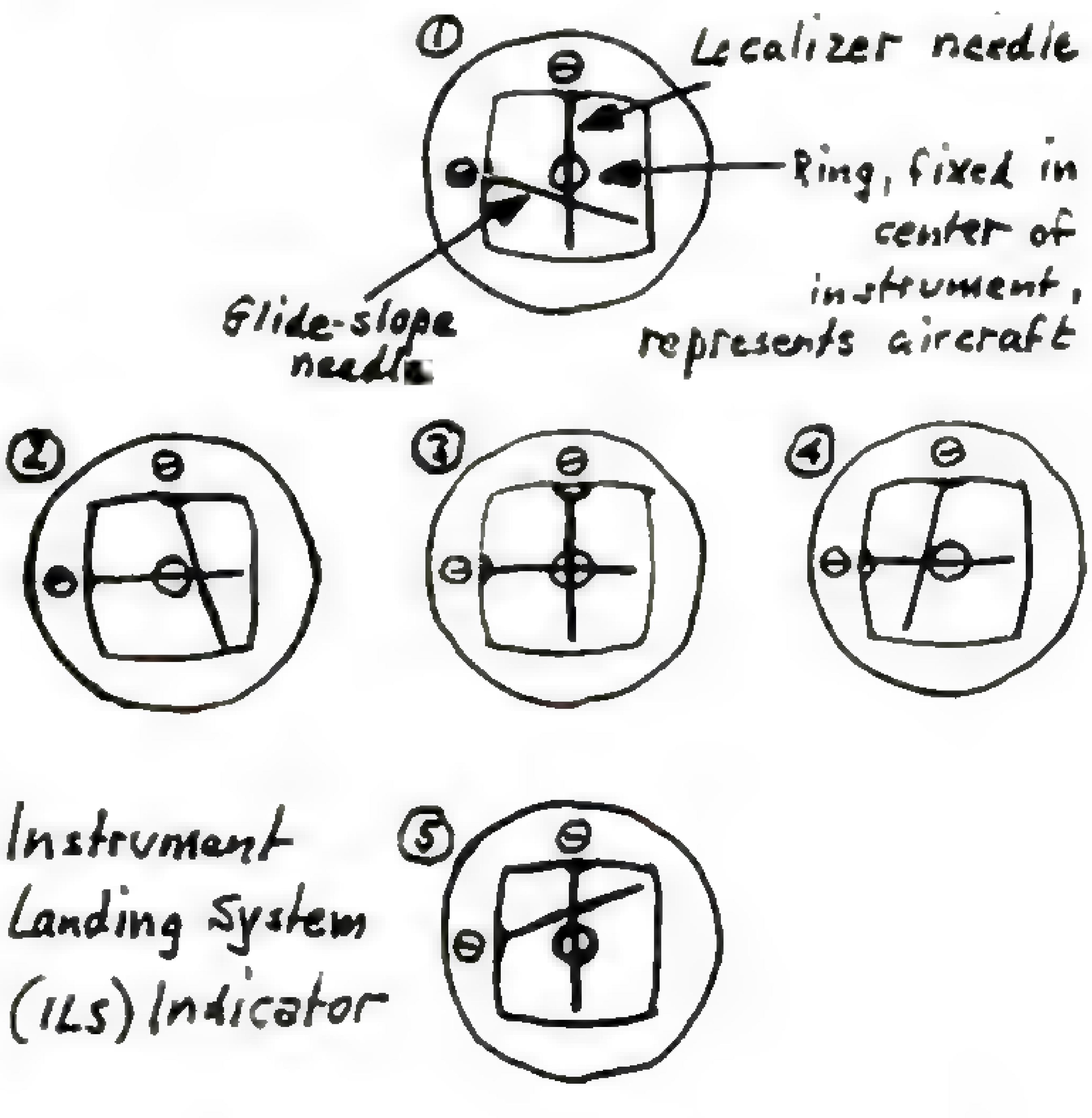
To "fly" a rocket booster manually, an astronaut could very well take over the function of the autopilot. The guidance signals, instead of being wired directly into the control "loop," would have to be displayed on the instrument panel in suitable form for the astronaut to see and act upon.

A Rocket-Piloting Indicator

This display could take the form of the conventional ILS (instrument landing system) indicator used by aircraft in instrument approaches to runways during conditions of low ceiling and poor horizontal visibility.

The ILS indicator has two crossing needles. One, the "localizer needle," turns right and left. The other, the "glide-slope needle," moves up and down. (See my sketch below.)

In order to stay lined up with the runway, the pilot has to keep the vertical (localizer) needle centered. To de-



Indicated positions of aircraft with respect to correct position in landing-approach path: ① Too high ② Too far left ③ On approach path ④ Too far right ⑤ Too low

Dr. von Braun, director of Marshall Space Flight Center, escorts Mrs. Lyndon Johnson on First Lady's tour of the Huntsville, Ala., base. With scale model, in photo, he shows her how Saturn I rocket booster works.

Boosters?

scend so that he touches down at the near end of the runway, without hitting a tall building on the approach path, he has to center the horizontal (glide-slope) needle.

The basic problem of keeping a manually flown rocket on a prescribed boost trajectory is just the same as the instrument-landing problem. The only difference is that the term "climb slope" replaces "glide slope."

Q ***What are possible advantages of flying rocket boosters manually?***

A Probably this question can best be answered by looking again at time-tested procedures in aviation.

There is no technical reason in the world why the signal outputs of an aircraft's localizer and glide-slope receivers could not be fed directly into the plane's autopilot. In many aircraft it can even be done just by flipping a switch.

The sober fact of the matter, however, is that no airline in the world has yet authorized low-ceiling instrument approaches to be flown with the autopilot engaged. The reason is very simple. By removing himself from the "loop," the pilot loses that intimate touch with the situation that is required for corrective action in case of a sudden instrument failure.

Such a failure is not critical when the aircraft is several thousand feet up, where there is plenty of time for remedial action. But if a faulty autopilot produces, say, a hard-over, nose-down elevator deflection while an aircraft is coming in for a landing at 130 knots and just breaking out of a 200-foot overcast—well, there just isn't much time for the captain to make the transition from automatic to manual mode.

The same case can be made, and has been made, for manual control of rocket boosters during ascent. Suppose, during the high-speed ascent through the denser layers of the atmosphere, that a faulty servo actuator produces a hard-over deflection of one of the booster's rocket engines. How many seconds are left before aerodynamic forces will rip the booster apart and turn it into a fireball? When must the astronaut in command make the fateful decision to abort the flight by separating his spacecraft from the failing booster, and firing his escape rocket?

Not being "in the loop," he too may lose critical seconds in transition. This in turn may lead to the requirement of providing for "automatic abort"—and, needless to say, any such thing is exceedingly unpopular with astronauts. And rightfully so; for it is like telling a jet pilot, "Your plane is wired so that your ejection seat may be fired at any mo-

[Continued on page 174]

[Continued from page 73]

ment that a little black box decides you are in trouble."

Q ***Would manual control of boosters have any disadvantages?***

A One of the arguments against this is that a multistage space rocket would change its response to control-stick action continuously.

First, the aerodynamic forces change from zero (on the pad), through a maximum (usually a little over a minute after takeoff), and back to zero (in airless space). Second, since most of the takeoff weight is made up of propellants, the rocket loses a lot of mass as it builds up speed. Third, the occasional shedding of a stage, and the firing-up of the next-higher stage, further affect the control-stick response. Of course all these variations can easily be compensated for electronically. But then the question arises as to what will really have been gained by putting the astronaut into the control loop, if we still depend on so much automatic equipment.

With our very limited practical experience in manned space flight, it would probably be premature to try to settle this issue now.

But it is likely that the question of manual booster control will come up again and again in the future. As the traffic density of our space-flight operations increases, the question of recoverable and reusable boosters is bound to attract more and more attention. And obviously, by the time we put a pilot in a booster to fly it back, we must be prepared to say clearly whether or not he should also fly it up.

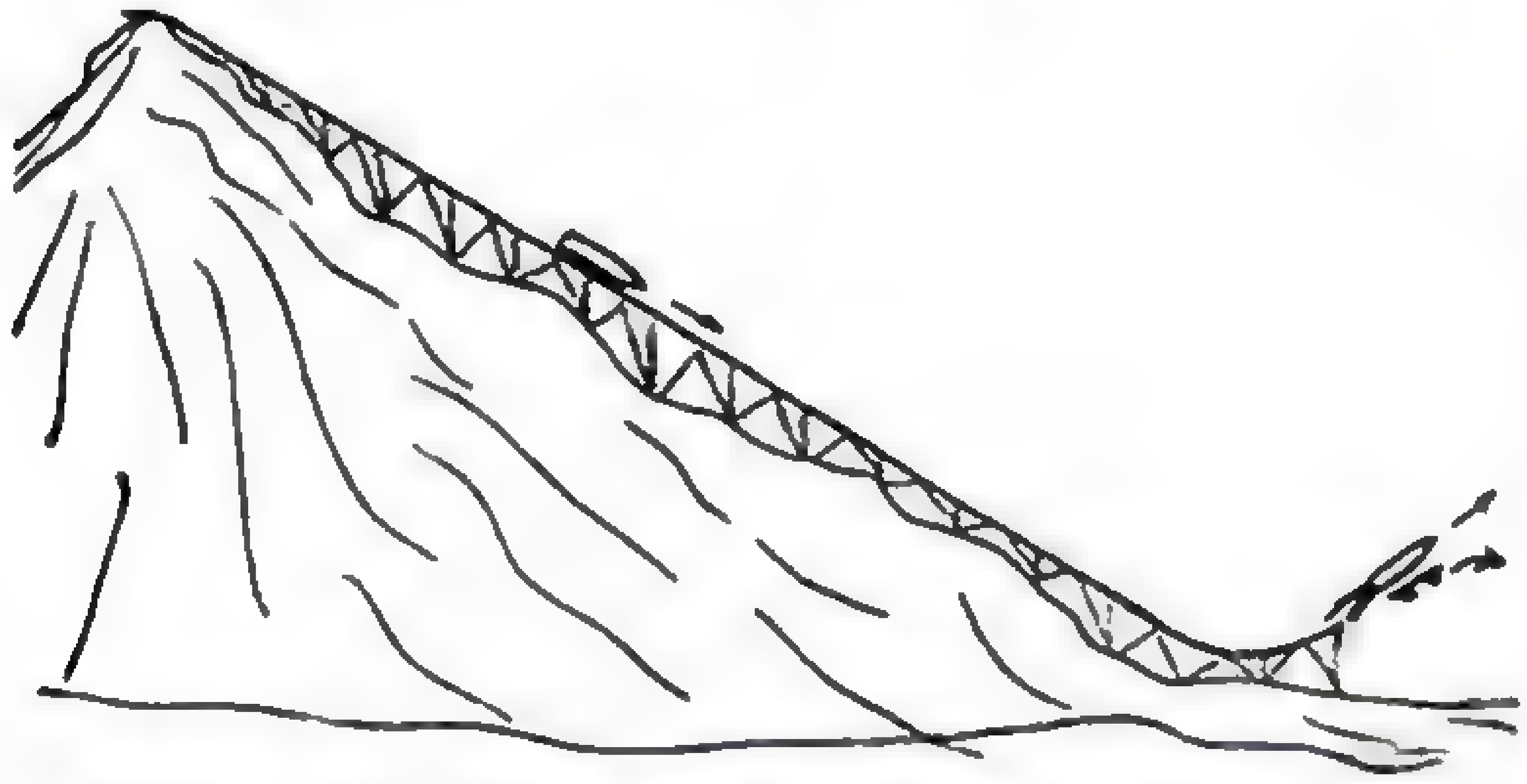
Q ***Is it feasible to give large rockets a mechanical boost?***

A In principle, yes. Just as airplanes can be catapulted from the deck of a carrier, it is entirely feasible to apply an initial mechanical boost in launching a rocket. And it is entirely true that any initial velocity imparted to a rocket by external means—that is, without drawing on the rocket's own supply of propellant—offers a potential gain in performance.

If the idea has not caught on, this is solely due to practical engineering and operational considerations. (Commercial

airports and military air bases do not use catapulting equipment, either.)

Many schemes for mechanical-boost systems for rockets have been suggested. Proposals range all the way from simple pulley-and-counterweight arrangements to mile-long pneumatic launch tubes; and from underwater launching, utilizing a rocket's buoyancy, to long inclined tracks on which a sled-mounted rocket comes racing down a mountain—ultimately to be hurled up into the air like a ski jumper, by an upward-sloping ramp. How this last idea has been envisioned is sketched here.



None of these suggestions violates any law of physics. The drawbacks of all these schemes come to light when one goes into details.

Difficulties Arise in Practice

To permit the high accelerations and the strong local "grab" forces involved in most of these mechanical-boost systems, for example, a large rocket's structure would have to be substantially reinforced. This often adds enough dead weight to cancel the gain from the boosting.

Underwater launchings of large rocket craft using high-energy propellants, such as liquid hydrogen and liquid oxygen, turn out to be not nearly as simple as those of Polaris rockets burning low-energy solid propellants.

And, finally, long sloping ramps are incompatible with the practical necessity for variations in the launch azimuth, or compass direction, of firing. Besides, Cape Kennedy—otherwise an ideal site for space launchings—has no mountains higher than 10 feet! ■ ■

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Dangerous Dams— Disasters Waiting to Happen

A Startling Nationwide Report by PS

What Happens to All That Horsepower?

PAGE 48

Tools for Working On Your Car—12 Pages

Dr. Wernher von Braun looks ahead to—

Atomic Power for

IN AN earlier issue Dr. von Braun briefly told of two different kinds of nuclear rockets under current development: "blowdown" and "ion" types.

Now he answers PS readers' questions about the engineering problems of nuclear blowdown rockets—the first objective of our national nuclear-rocket program—referred to here simply as "nuclear rockets."

Q ***What makes a nuclear rocket go?***

A The heart of a nuclear-rocket engine, of course, is the reactor that converts nuclear energy into heat.

The fuel consists of a special kind or "isotope" of uranium metal, called U-235. When properly bombarded with neutrons, the uranium nuclei break up or "fission" into a pair of fragments apiece—and emit more neutrons in the process, thus keeping the reaction going.

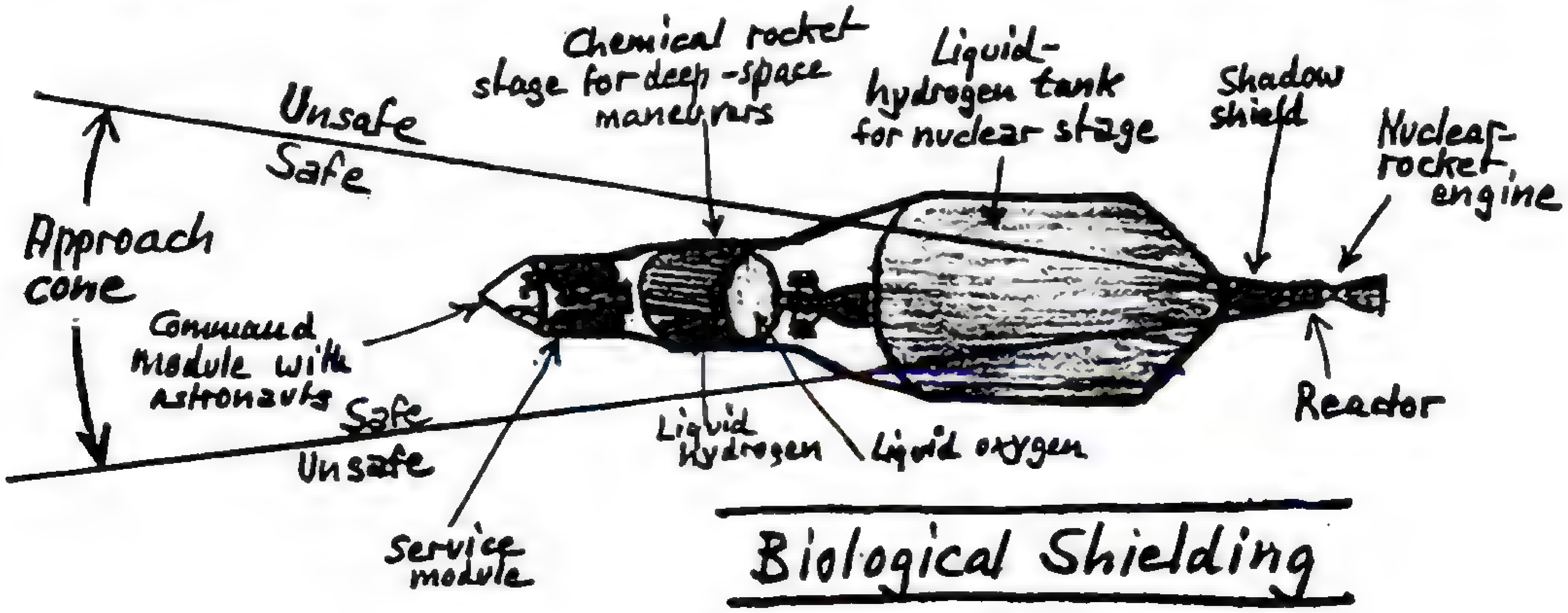
The fission process releases energy, because the sum of the binding energies required to hold together the two fragments is less than the binding energy of the original U-235 nucleus. The excess energy is carried away by the pairs of fragments, by the neutrons, and by gamma rays. Since all of the fragments and most of the neutrons and gamma rays are stopped within the reactor, the bulk of the energy that is released by U-235 fission will heat the reactor.

For a nuclear-rocket engine to be thermally efficient, the reactor's temperature must be as high as possible. The melting point of uranium, 2,070 degrees F., sets a theoretical limit. Graphite, which withstands far higher temperatures, makes a very good material for the reactor's "moderator," which slows down ejected neutrons to a speed at which they are more likely to trigger more uranium fissions. So all present experimental reactors for nuclear-rocket engines are made of U-235 metal powder embedded in graphite.

For the reactor to operate at a constant power level, an average of exactly one neutron from each fission must cause another fission. All excess neutrons must be otherwise disposed of.

In a given nuclear-rocket engine design, a more-or-less fixed percentage of neutrons is lost through leakage to the outside and, particularly, through particle absorption not leading to fission. The remaining neutron balance can be adjusted with control rods of neutron-absorbing material, by varying the depth of their insertion in the reactor.

This control problem is greatly simplified by the fact that some of the neutrons (a little less than one percent) are "delayed"—emitted, not at the instant of fis-



Rockets

sion, but over a period of seconds afterward. This permits us to use relatively sluggish controls to keep the reactor at the desired power level.

Q ***How does the reactor's heat drive a nuclear rocket?***

A Just as in a chemical rocket engine, liquid-hydrogen propellant is pumped into the cooling jacket of the engine's exhaust nozzle. Gradually warming up, it flows upward through a "reflector" (which reflects outward-bound neutrons back into the reactor) to the engine dome, where it is turned around.

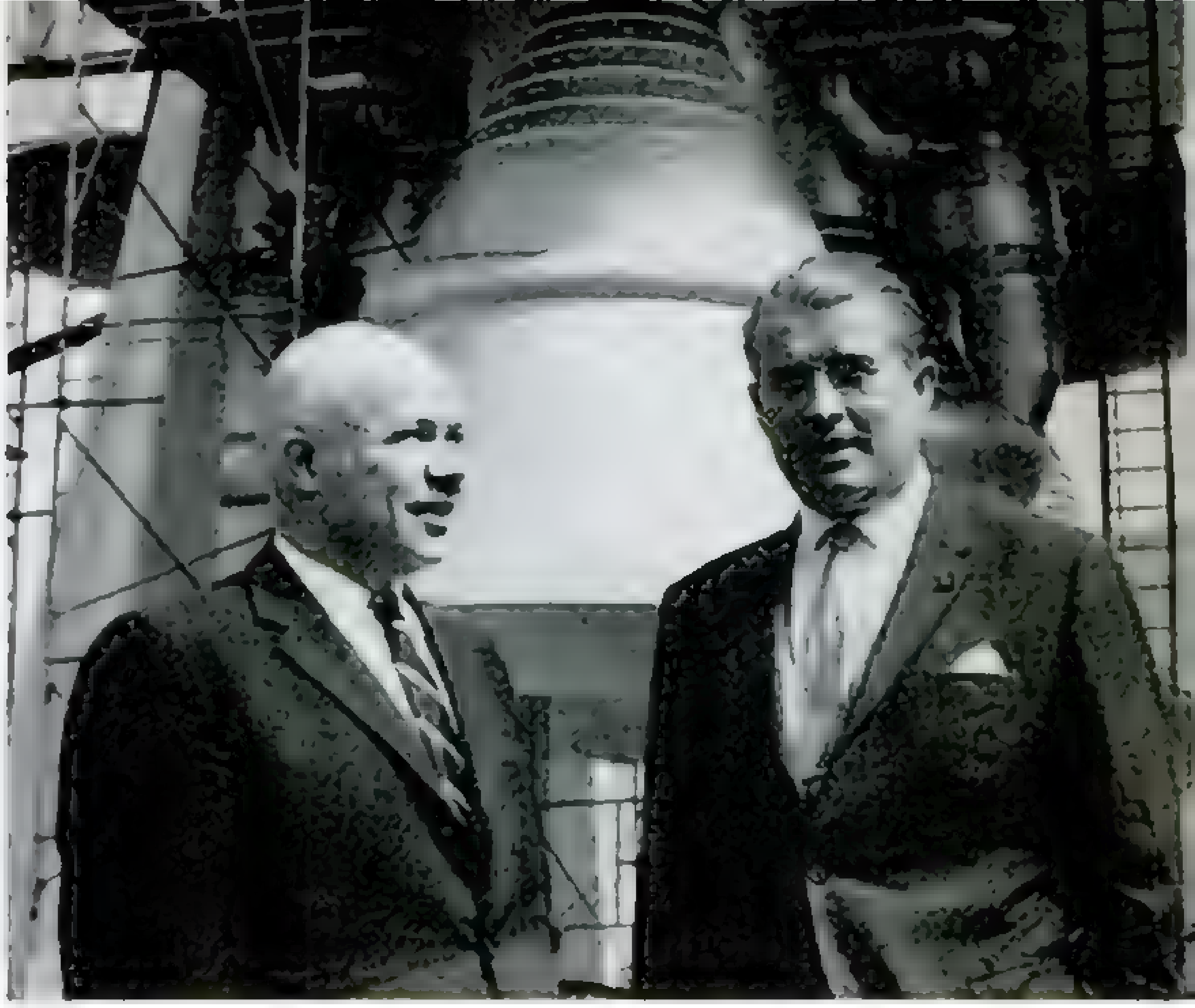
By now a cold gas, the hydrogen enters several hundred narrow passages drilled through the graphite-uranium reactor core—and is heated almost to the white-hot reactor's operating temperature. Emerging from the passages, the hot gas expands through a conventional DeLaval nozzle, in which it attains supersonic speed. The exhaust of a nuclear-rocket engine can be expected to reach 23,000 to 30,000 feet per second.

In terms of propellant economy, this means we get almost twice as much thrust out of every pound of propellant pumped in, as from a rocket engine using chemical combustion of hydrogen and oxygen.

Q ***Does a nuclear-rocket engine pose radiation problems?***

A Yes, many—but they need not cause unacceptable hazards.

Probably the nastiest radiation problem is that the engine remains "hot" even after being shut down. The viciously radioactive atomic fragments created by the fission process keep emitting beta and gamma rays, which taper off only over a period of weeks and months.



PS Editor Bob Crossley and Dr. von Braun preview Saturn V rocket on display at U.S. Space Park, a top exhibit at New York World's Fair.

This means that, unlike chemical engines, nuclear-rocket engines cannot be personally inspected after a static run. They must be placed in "hot cells" where they can be viewed only through multi-layered shielding windows, and disassembled or worked on only with remote-control manipulators. Even tankage used during static runs must be detached from the engine and sent to a "cool-down" facility before it can be moved back into a normal assembly shop. This situation makes it virtually impossible to static-test a nuclear-rocket engine prior to its shipment to the launch site.

Another radiation problem involves the safety of astronauts riding a nuclear rocket. While inside their spacecraft in the rocket's nose, they are protected by a substantial amount of radiation-absorbing material, located between them and radiation from the engine. This can greatly reduce the weight of the "shadow shield," indicated in my sketch on the opposite page, that must be placed directly above the engine.

However, many uses of nuclear rockets will involve rendezvous maneuvers in orbit, as for changing ships, changing crews, and orbital refueling. Approach for rendezvous and docking will be permissible only through the protected "approach cone" shown in my sketch.

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Next, radiation causes a heating problem for parts near the rocket's engine.

A nuclear-rocket engine that produces 100 tons of thrust runs at a reactor power level of several million kilowatts. In a well-built nuclear-rocket engine, only about one percent of the energy escapes in the form of gamma and neutron radiation—but, for the power level cited, that still amounts to tens of thousands of kilowatts! Think of the heat radiated even by a puny 100-watt lamp, and it is easy to understand why parts near a nuclear-rocket engine may need active cooling, by suitable routing of the flow of liquid hydrogen to the engine.

Aside from its heating effects, the radiation emitted by the reactor has a rather unwholesome effect on many construction materials used in rockets. Metals behave reasonably well, but the lifetime of organic and plastic materials such as rubber, teflon, or polyurethane is greatly reduced, and even glass loses its transparency rather rapidly. Particularly vulnerable are electronic solid-state devices such as transistors—which must either be banned from nuclear rockets, or put in heavily shielded boxes.

Interestingly, the dreaded "fall back" or explosion on the launch pad constitutes no serious radiation hazard—simply because all nuclear rockets are likely to be chemically boosted anyhow. So the reactor, never having been operated, is free from dangerous radioactive fission products.

But special precautions are needed to keep a nuclear reactor from falling into the sea. Water entering the tubular channels in which hydrogen passes through the reactor core can drastically upset the delicate neutron balance—with the result that the reactor may "go critical" and destroy itself. While the energy released in such an incident would not be comparable with that of an atomic bomb, the effect would still be a low-yield explosion, accompanied by a formidable burst of neutron and gamma radiation. To prevent such an occurrence in case of a launch mishap, provisions for emergency destruct of the reactor may be a mandatory requirement.

Q ***Can a nuclear-rocket engine be abruptly started and shut down?***

A No. The tremendous difference between the original temperature of the liquid hydrogen (−423 degrees F.), and the white-hot temperature at which the reactor operates under full power, makes it necessary to start a nuclear-rocket engine relatively slowly. Otherwise, cracks in the reactor's brittle graphite-uranium core are unavoidable. Moreover, the increase in hydrogen flow through the reactor (controlled by the liquid-hydrogen feed pump) must be carefully synchronized with the increase in the reactor's power level (controlled by the position of its control rods).

Reactor shutdown poses an even more severe problem. During power operation the reactor has contaminated itself with highly radioactive fission products. For a few minutes, these keep emitting such a strong "decay radiation" that the reactor core would soon be heated to destruction unless one kept up an adequate flow of hydrogen through its passages.

This "aftercooling" of nuclear-rocket engines is not necessarily wasteful. How much hydrogen will be needed to prevent the core from overheating is known beforehand. Thus, on a typical space mission, one would shut down the nuclear engine shortly before the required flight velocity had been reached. The missing balance of the speed would be produced by the exhaust of after-coolant heated by the decay radiation.

Q ***How will nuclear rockets be used?***

A The most promising uses seem to be:

- For upper stages of large chemically boosted rockets, particularly in missions requiring very high final velocities.
- For supply vehicles shuttling back and forth between a low earth orbit and an orbit around the moon (with hydrogen reloading during each stopover in earth orbit).
- For planetary space vehicles beginning their voyages in earth orbit. These vehicles may be assembled in orbit, from parts and propellants brought up by several chemically powered rockets.

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Man to the Moon
PS Puts You in the Pilot's Seat

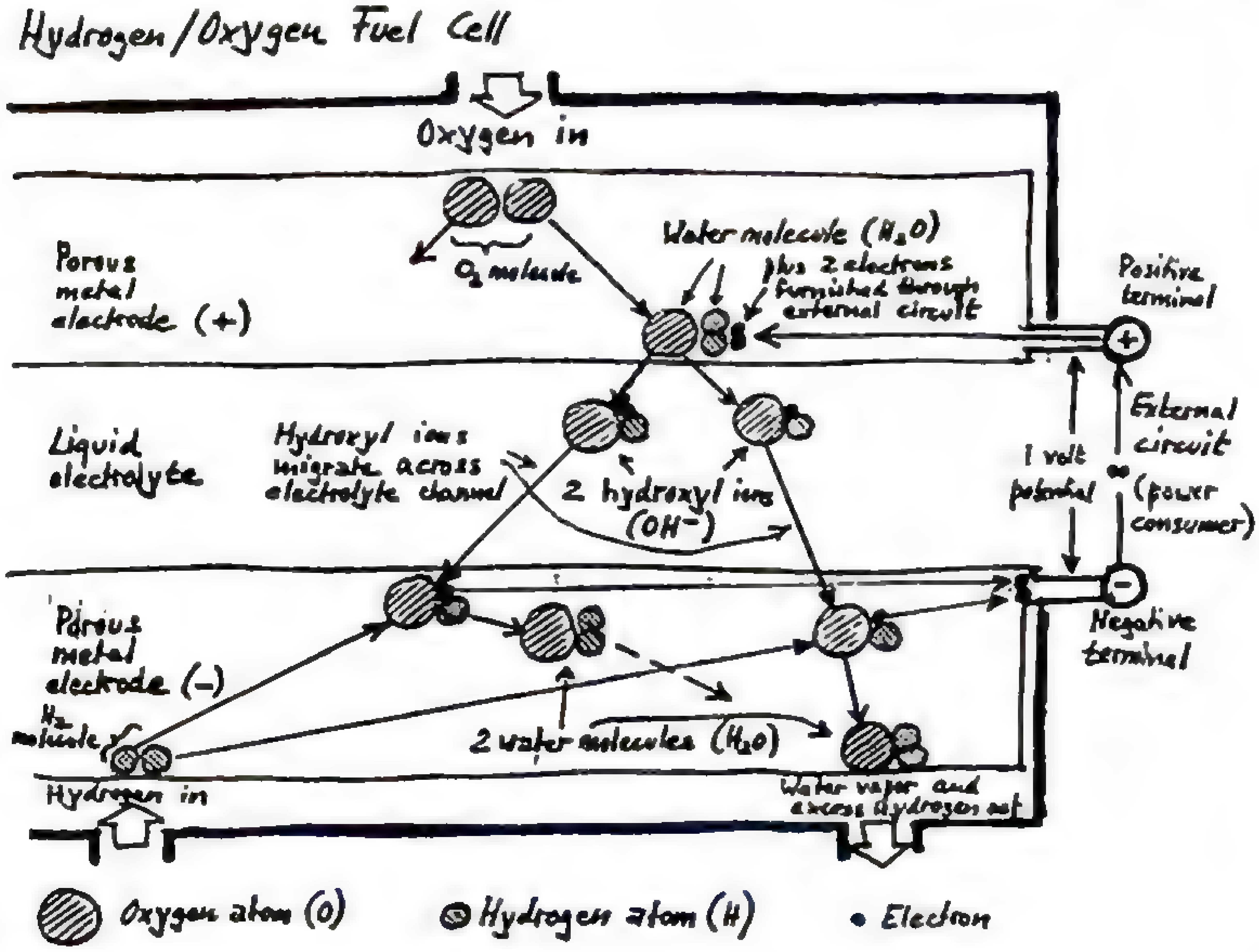
Dr. Wernher von Braun tells how we'll get

Space Power from

Q ***What is a fuel cell?***

A It is an exciting new device capable of converting fuel and oxygen directly into electricity. Its efficiency is easily twice as high as that of conventional power sources. Like so many revolutionary technical concepts, the fuel cell is the direct result of the extraordinary demands of the space age.

The most advanced fuel cell uses hydrogen and oxygen, both in gaseous form. What it does amounts to the reverse of the familiar schoolroom demonstration of electrolysis. In that experiment, sending a direct current through water breaks up the water molecules, with the hydrogen gas bubbling up at one electrode and oxygen gas at the other. In the fuel cell, just the opposite happens: Hydrogen gas and oxygen gas are fed in, and out comes an electric current—and a little water.



Q ***What will fuel cells be used for?***

A Because of their light weight, fuel cells offer an almost ideal source of power for space vehicles. General Electric fuel cells will provide electric power for the two-man Gemini spacecraft, while Pratt & Whitney fuel cells will be used in the follow-on Apollo spacecraft to land Americans on the moon.

In our space program the use of fuel cells is firmly established, not only in spacecraft, but likewise in future space stations and even on the moon's surface.

One of the most important aspects of the fuel cell—the hydrogen-oxygen fuel cell, in particular—is its by-product, water. The water from a fuel cell is potable. You can drink it as it comes out of the cell stack—and astronauts need about 6.6 pounds of water a day for life support. Also, with the help of electricity and electrolysis, water can be turned back into its two constituents, hydrogen and oxygen.

Suppose we power a vehicle roving the surface of the moon with fuel cells. Let us further suppose it is equipped with hydrogen and oxygen tanks for a radius of action of a few hundred miles. When the vehicle comes back to camp, its hydrogen and oxygen tanks may be nearly empty, but its water-collec-

Fuel Cells

In Cape Kennedy blockhouse, Dr. von Braun (right) and Dr. Kurt Debus, launch director at Cape, watch countdown for a Saturn launching—one of a series of successful trials of our biggest rocket.

tion tank, in return, will be almost full.

To "fill 'er up," the vehicle will pull into a lunar service station. This station need not be supplied with fresh hydrogen and oxygen flown in from earth. Instead, it has a large array of solar cells that convert energy from the sun into electricity. The driver of the lunar vehicle turns in his water, and his tanks are replenished with fresh hydrogen and oxygen generated in a high-pressure electrolysis plant. This plant's supply of water can, of course, be augmented by refuse water accumulated at a nearby lunar base.

It takes 25 square yards of solar cells to collect one horsepower from the sun. Thus it would be awkward, if not impossible, to operate a bouncing cross-country moon rover directly with solar power. But there is nothing wrong with large solar-cell areas at the filling station to "reprocess" turned-in water in a round-the-clock operation.

The fuel cell as a source of power for lunar-surface vehicles thus becomes a convenient energy-storage device, operating a bit like a car battery. The important difference is that, for the same amount of stored electric energy, it is much lighter.

Q ***How does a fuel cell work?***

A The hydrogen-oxygen fuel cell (the easiest to explain) operates as shown in my larger sketch, which draws upon material published by Pratt & Whitney. Oxygen gas (O_2) enters at the top, and hydrogen gas (H_2) at the lower left corner. The two gases are fed into porous metal electrodes that are separated by a solution of potassium hydroxide, an "electrolyte" or electrically conductive liquid. At the electrodes occurs an important ion exchange, the key to generating electric power. The basic mechanism (as sketched) works as follows:

One oxygen atom (of the two making up an O_2 molecule), plus one water molecule (H_2O), plus two electrons, produce two hydroxyl ions (OH^-). These hydroxyl ions migrate across the electrolytic "channel." Within the porous hydrogen electrode, each hydroxyl ion latches onto one hydrogen atom (of the two making up an H_2 molecule).

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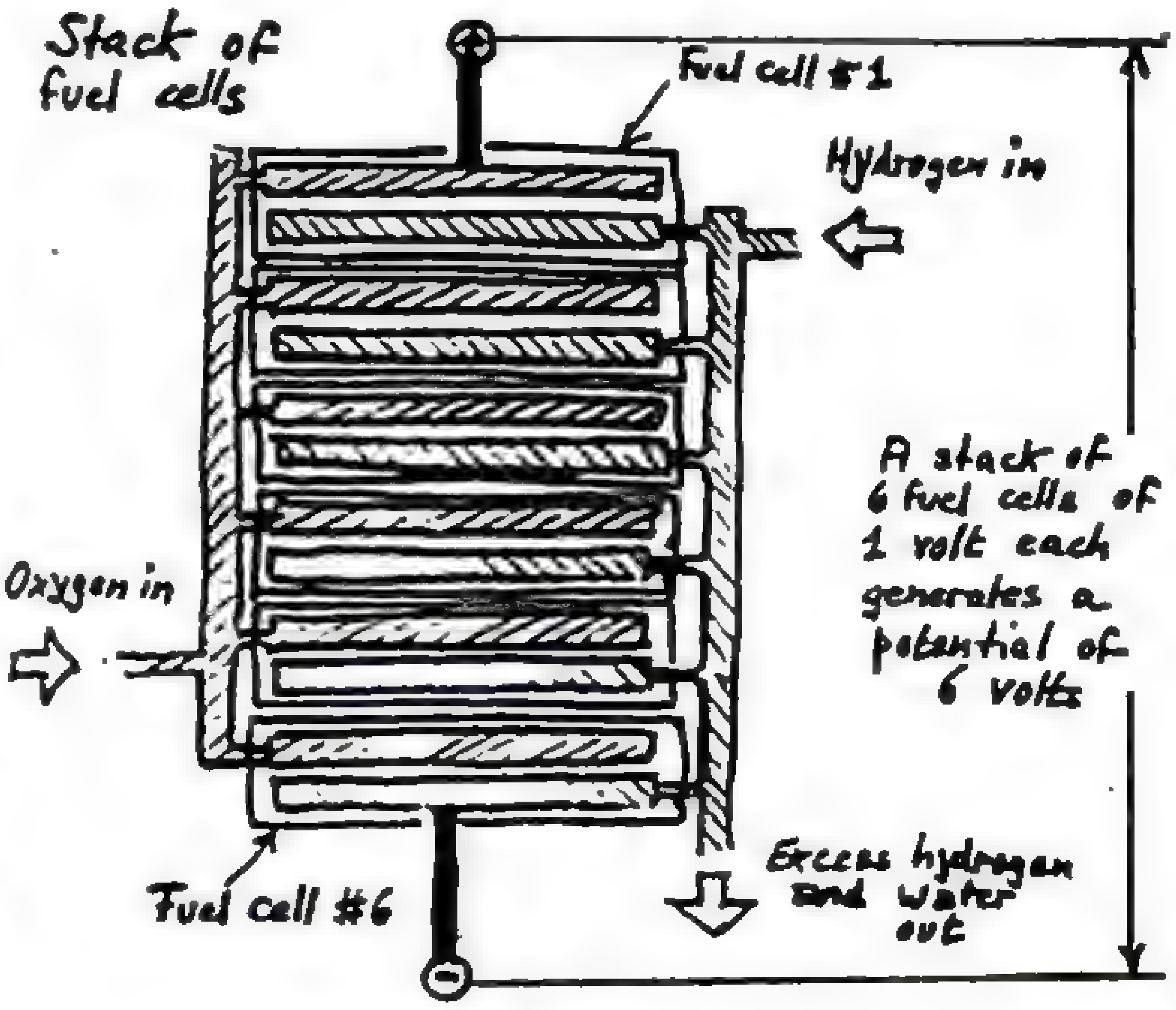

Space Power from Fuel Cells

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Two molecules of water and two free electrons are the result. The water is removed by way of an outlet at the lower right corner. The two free electrons are extracted at a terminal attached to the negative (hydrogen) electrode, which has a potential of about one volt against the positive (oxygen) electrode.

In terms of hydroelectric power this is like saying the storage lake (the negative electrode) is at a higher elevation than the drain-off river (the positive electrode). Like the water rushing through the turbines at a dam, the current of electrons produced within the negative electrode can perform useful work, in an external circuit, before reaching the lower energy level of the positive electrode. Re-entering the cell there, the electrons hitch-hike back through the electrolyte to their starting point on new hydroxyl ions.

One volt, of course, is not much—it is about half the voltage of a flashlight battery. But just as in a flashlight, or in a car battery, we can stack cells together "in series" to multiply the voltage. My second sketch shows how this is done.

Despite its high efficiency, a fuel cell still generates, besides useful electricity, a certain amount of heat that must be dissipated to protect the cell. The heat is carried away by running the cell with an excess supply of hydrogen gas. This excess hydrogen also serves to drive the water generated by the fuel cell's operation to its outlet. If the water were not removed, the cell would soon "drown."

The excess hydrogen now can either be cooled in a radiator and readmitted to the cycle, or simply vented away. The choice depends on a trade-off between equipment weight and propellant weight. For longer operating time, cooling and re-using the hydrogen is preferable. For shorter operation, the blow-away scheme is superior, since it does not require a cooler.

Q ***Why do fuel cells surpass other power sources in efficiency?***

A Ever since the beginning of the industrial revolution, combustion of fuel has been the prime mover of all the many wheels that have started to spin. Whether in a steam or a diesel locomotive, a piston-powered automobile, or a jet-powered air-

plane—whether directly as in a rocket, or indirectly as in a kitchen fan (which gets its power from an electric outlet powered by a turbogenerator in a municipal utility plant)—we could always trace the source of power back to some device that burned combustible fuel, such as crude oil, natural gas, gasoline, or coal, with oxygen from the air. The fuel cell is a drastic departure from this time-honored process.

All conventional engines are restricted to what engineers call the "Carnot-cycle efficiency." Nicolas Leonard Sadi Carnot, a French scientist, showed that even under ideal conditions—the Carnot cycle—a heat engine cannot convert into mechanical energy all the heat energy supplied to it.

In a Carnot cycle, an engine accepts heat energy from a high-temperature source, such as hot steam from a boiler, or the combustion of gasoline in the cylinder of a piston engine. It converts part of the energy into mechanical work—for instance, by allowing the steam or combustion gas to push against a piston or a turbine blade. But to keep the process going, the engine must reject the rest of the energy, to a "heat sink" or cold body.

This is the reason that automobiles need water cooling and radiators, aircraft engines need air cooling, and steam turbines need water-cooled condensers. For Carnot showed that in order to increase the efficiency of a heat engine, it is necessary to increase the temperature *difference* between the heat *source* and the heat *sink*. Heat engines are limited to overall efficiencies of the order of 30 percent by the inherent restrictions of this Carnot cycle.

The fuel cell is not tied to this cycle. Efficiencies of 60 percent and more have been demonstrated. Hence, the great interest in this byproduct of the space age.

Q ***Will fuel cells be used only in space?***

A It is a safe bet that they will find increasing acceptance on earth, too. Recently a fuel-cell-powered tractor was demonstrated. Fuel cells running on oil and natural gas, rather than hydrogen, are already being tested. While it may be premature to predict imminent doom for the conventional heat engine, many believe that the days of any engine restricted by the Carnot cycle are numbered. ■ ■

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QUINTS—
Could It Happen to You?

Special!
THE NEW NAVY
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Wernher von Braun: Do Rockets Need Fins?

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Dr. Wernher von Braun explains:

Why Rockets Have

What are fins on rockets for?

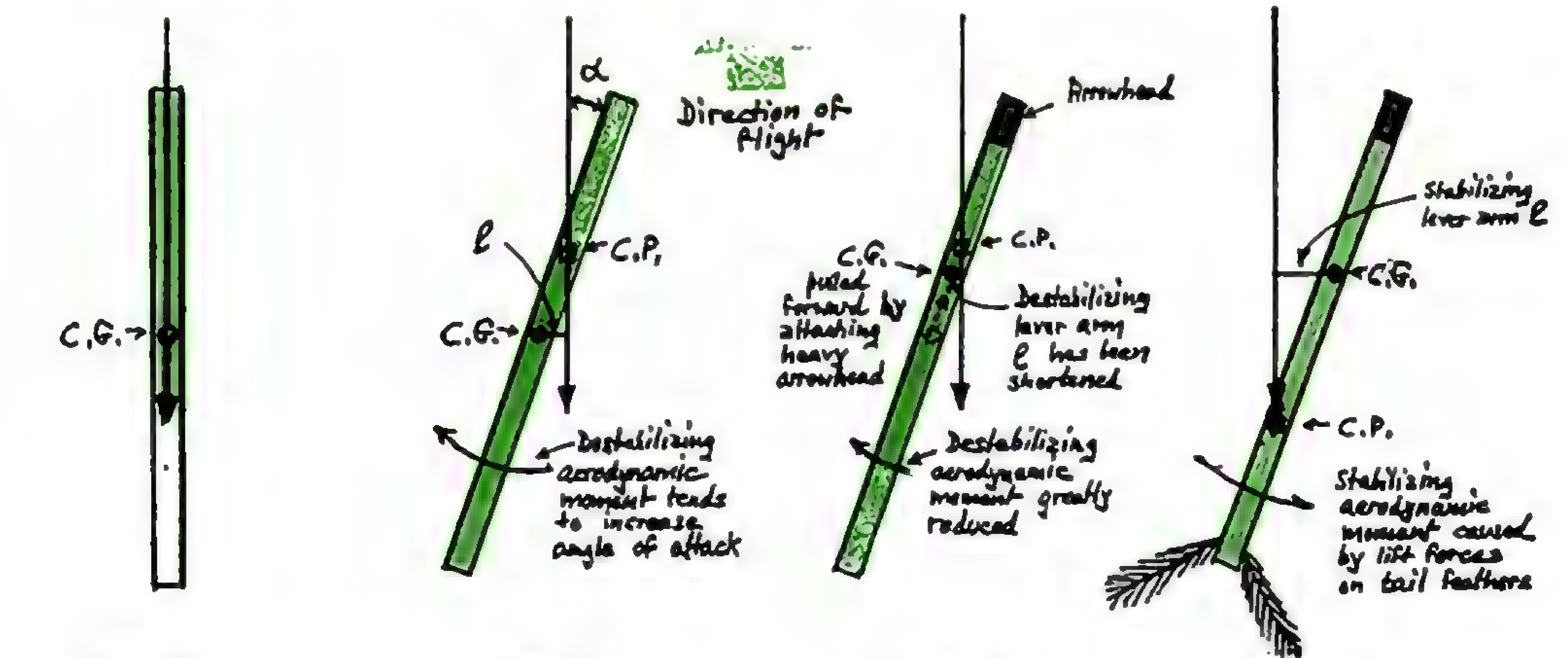
The fins serve the same purpose as an arrow's tail feathers. They provide aerodynamic stability during flight through the atmosphere by pulling the so-called Center of Pressure (C.P.) behind the Center of Gravity (C.G.).

Let us experiment with an arrow. We remove the head and tail feathers and shoot the bare stick from a bow. It tumbles wildly. We replace the head and shoot again. The tumbling is slowed. We stick the tail feathers back on—and the arrow flies straight. Now let us look into this varying behavior:

The bare stick's Center of Gravity is at its geometrical center (as balancing it on a wedge verifies). So long as the stick flies straight (Case 1 in my sketch below), the combined retarding force due to air drag will pass through the Center of Gravity. Since there is no leverage between the force and the C.G., there can be no stabilizing or destabilizing moment (turning effect).

But now assume that for some reason—say a crosswind or gust—an ever-so-slight misalignment occurs between the aerodynamic force and the stick's center line (Case 2 in sketch). The air stream now hits the stick at an "angle of attack," α (alpha). In the sketch, the fictitious force pushing against the stick at one point represents the combined effect of all the tiny little forces on the stick's entire surface. The Center of Pressure, by definition, is the point where this fictitious force intersects the stick's center line—and in Case 2, it is forward of the C.G. Acting on a lever arm *l*, it creates a moment that tends to *increase* the angle of attack. This condition is called *aerodynamic instability*.

Why is the Center of Pressure *forward*



Case 1
No angle of attack
No aerodynamic moment

Case 2.
Angle of attack α
Center of Pressure forward of Center of Gravity
Aerodynamic instability

Case 3
Arrowhead pulls Center of Gravity closer to Center of Pressure.
Still slight aerodynamic instability

Case 4
Tail feathers pull Center of Pressure behind Center of Gravity.
Aerodynamic stability

Fins

Dr. von Braun, right, shows rocket models to Prof. George B. Kistiakowsky of Harvard, chemistry-award winner and former science adviser to President Eisenhower.

of the geometrical center? Air pressure is highest at the blunt frontal area—where onrushing air is brought almost to a stop before being swept aside. (This is obvious in the case of zero angle of attack, and still holds true for a moderate angle of attack.) *Ram drag* created by this frontal area considerably exceeds the air's *friction drag* along the side of the stick. So most of the drag occurs in the forward part of the stick.

When we reattach the arrowhead (Case 3 in sketch), the heavy load moves the Center of Gravity forward—but still not as far forward as the Center of Pressure. Two factors cause the slower tumbling: We have shortened the lever arm between the C.P. and C.G., reducing the destabilizing moment; and by adding weight to the arrow's nose, we have increased the inertia of its mass and, thus, its resistance to abrupt rotational movements.

The arrow flies straight when we stick the tail feathers back on (Case 4 in sketch) because, as soon as an angle of attack develops, the winglike feathers generate aerodynamic lift forces—which, acting on a lever arm l, tend to *decrease* the angle of attack. This condition is called *aerodynamic stability.*

On rockets, fins are used because in many cases it is desirable to give a rocket aerodynamic stability.

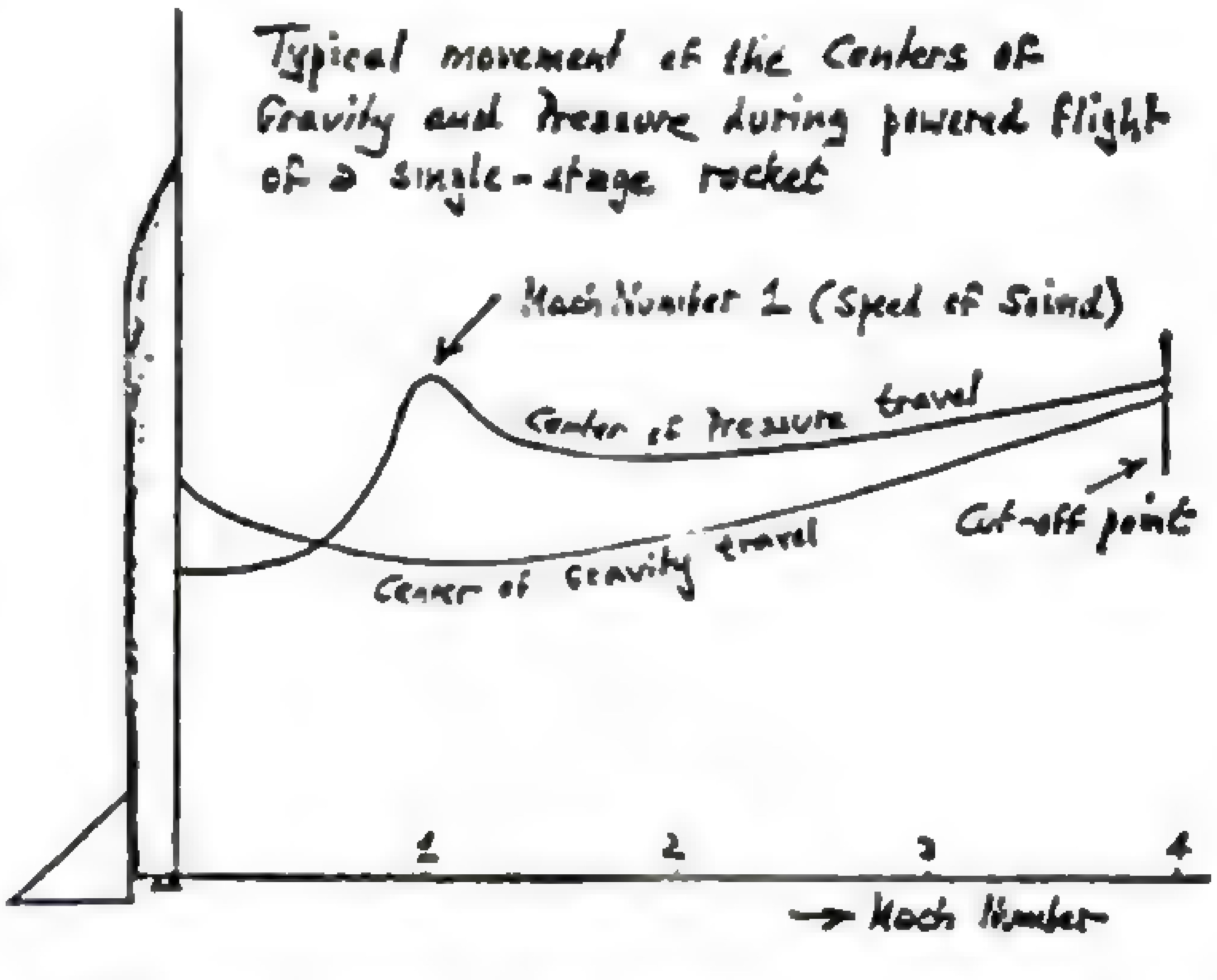
But why do some rockets have fins, while others don't?

That depends upon how important it is, in any particular case, to improve a rocket's aerodynamic stability.

Today, autopilot systems are available with fast enough response to steer rockets through the atmosphere no matter how unstable they are aerodynamically. Fins cost weight and drag, and can easily get misaligned by rough handling.

Therefore, all our modern long-range military missiles are finless—Minuteman and Polaris, and their predecessors Atlas, Titan, Jupiter, and Thor.

To steer aerodynamically unstable rocket missiles through the atmosphere is no mean trick. In the early days of missilery it just couldn't be done. That's why the V-2, Corporal, Viking, Sergeant, and Redstone sported fins.



The problem was not only the lack of adequate autopilots to cope with aerodynamic instability. Even more critical was the difficulty of pinning down the exact operating criteria to which the autopilot had to be tuned.

A typical long-range rocket takes off at velocity zero and a launch-site elevation not too far from sea level.

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Why Rockets Have Fins

[Continued from page 69]

In a minute or so it reaches Mach 1, the velocity of sound; and a minute later, it is speeding along through airless space at between Mach 5 and 15. During all this time the rocket's Center of Pressure travels quite a bit up and down, being highly sensitive to the Mach number at any instant. Meanwhile the Center of Gravity moves back and forth as the rocket burns up its propellants. (See my second sketch.)

Simultaneously the rocket's mass is rapidly shrinking—and with it, the all-important "mass moment of inertia," the ability of the rocket's mass to oppose abrupt rotational movements.

Thus it is quite a trick to devise a rocket autopilot that can adequately cope with all these rapidly varying conditions. In fact, it is possible only by changing the "gain settings," the autopilot's tuning, several times in flight. Understandably, this rather sophisticated technique was not available for the early "birds." But today it is old hat.

Q ***Then why do we still build some rockets with fins?***

A Fins on rockets still offer great advantages in two applications.

One is for *antiaircraft (and antimissile) rockets.* Unlike a long-range rocket, whose usual purpose in life is to carry a warhead from point A to a well-defined and stationary point B, the antiaircraft or antimissile rocket doesn't know, at the instant of takeoff, exactly where its warhead will go off.

Since the target may perform evasive maneuvers, the intercepting rocket must continuously adapt its own flight path accordingly, on the basis of latest radar information of the target's movement. It has been suggested to use "path adaptive adjustments" of the autopilot, but antiaircraft-missile designers still prefer fins to simplify their complex control problem.

Antiaircraft rockets usually have rather large fins on their booster stages. During the boost phase, these rockets often fly without any active guidance or control—depending solely on their arrow stability and aimed only in the general direction of intercept, with the aid of ground launchers that can be rotated in azimuth and eleva-

tion. Only after booster drop-off does the rocket's guidance system take over.

For *manned rockets,* too, fins offer a definite advantage. Since the flight path—usually into orbit—is predetermined, and thus ideally suited to programed changes in gain setting, it might appear that there should be no need for fins. The problem of manned rockets, however, lies in the area of emergency provisions—more specifically, in what we call "abort procedures."

Suppose a large launch vehicle such as Saturn V has a serious autopilot failure at the most critical part of its ascent through the atmosphere—the "high-stagnation-pressure" period when the speeding rocket bucks the most severe aerodynamic forces. A failure in a swivel actuator may throw one of the five booster engines into a "hard-over" deflection, while an additional electrical failure may prevent the other engines from counteracting the unwanted turning moment.

In such a case, if high inherent aerodynamic instability assisted in rapidly increasing the angle of attack, structural overload might break up the rocket before the astronauts in the Apollo Command Module, triggering their escape rocket, could put a safe distance between themselves and the ensuing fireball in the sky.

It is in this area of crew safety that fins come in handy. In Saturn V the booster fins are not to provide perfect aerodynamic stability under all conditions—that would take fins of excessive size. But the fins reduce the aerodynamic instability enough to make sure that the astronauts can safely abort, no matter what technical trouble may afflict their space vehicle.

Our aim is to reduce the "turning rate"—the rotational speed at which the aerodynamically unstable Saturn V, when stricken by an autopilot failure, would turn into an angle of attack at which its structure would be bound to fail. One might say the purpose of the fins is to extend the period of grace that the astronauts have to push the "panic button." ■ ■

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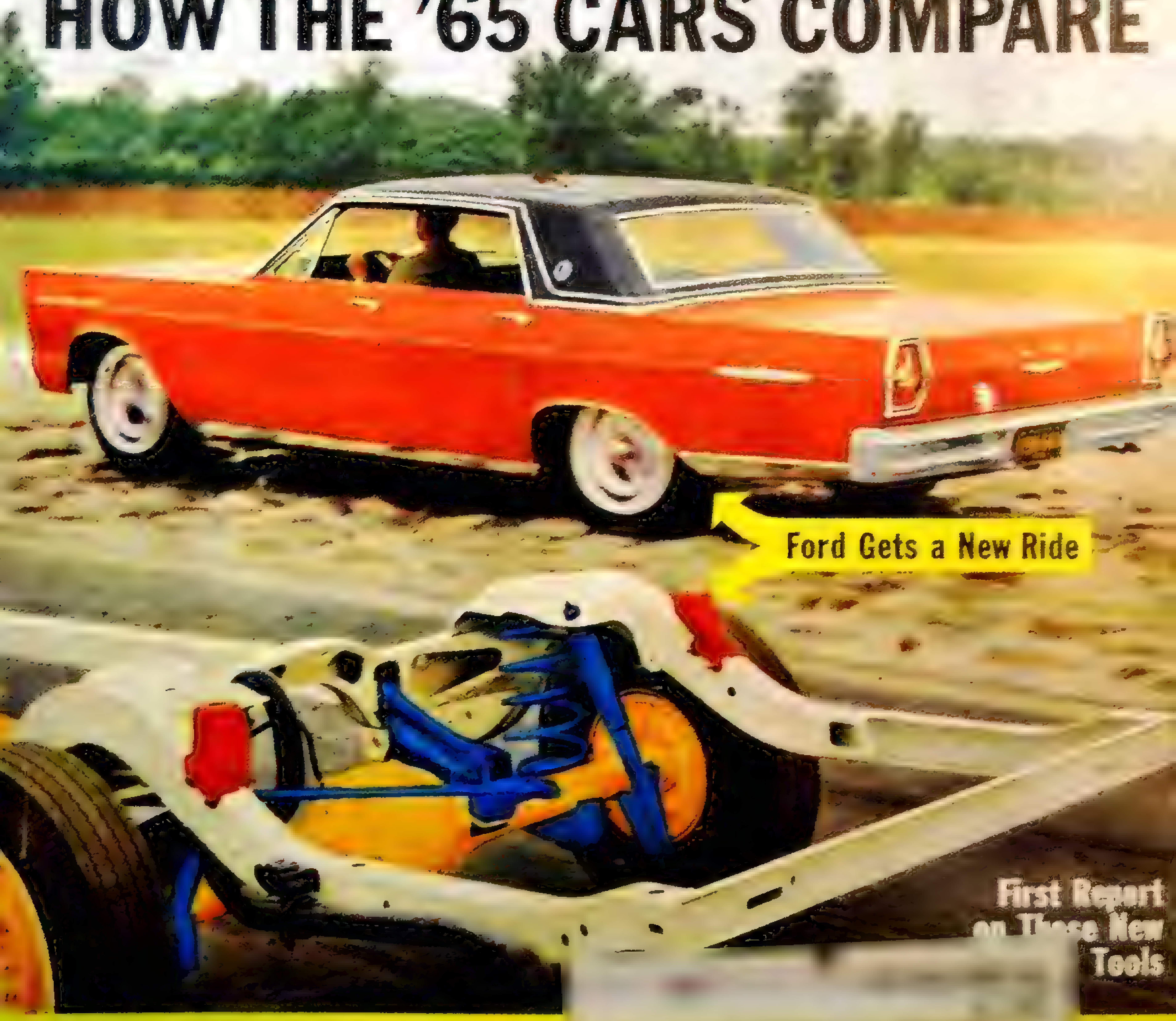
America's Most Famous Mechanic Answers Your Automotive Questions

HOW THE '65 CARS COMPARE



Latest Facts on Storm Doors—Flashing—Natural House Finishes

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Dr. Wernher von Braun tells

How Spacemen Can Use

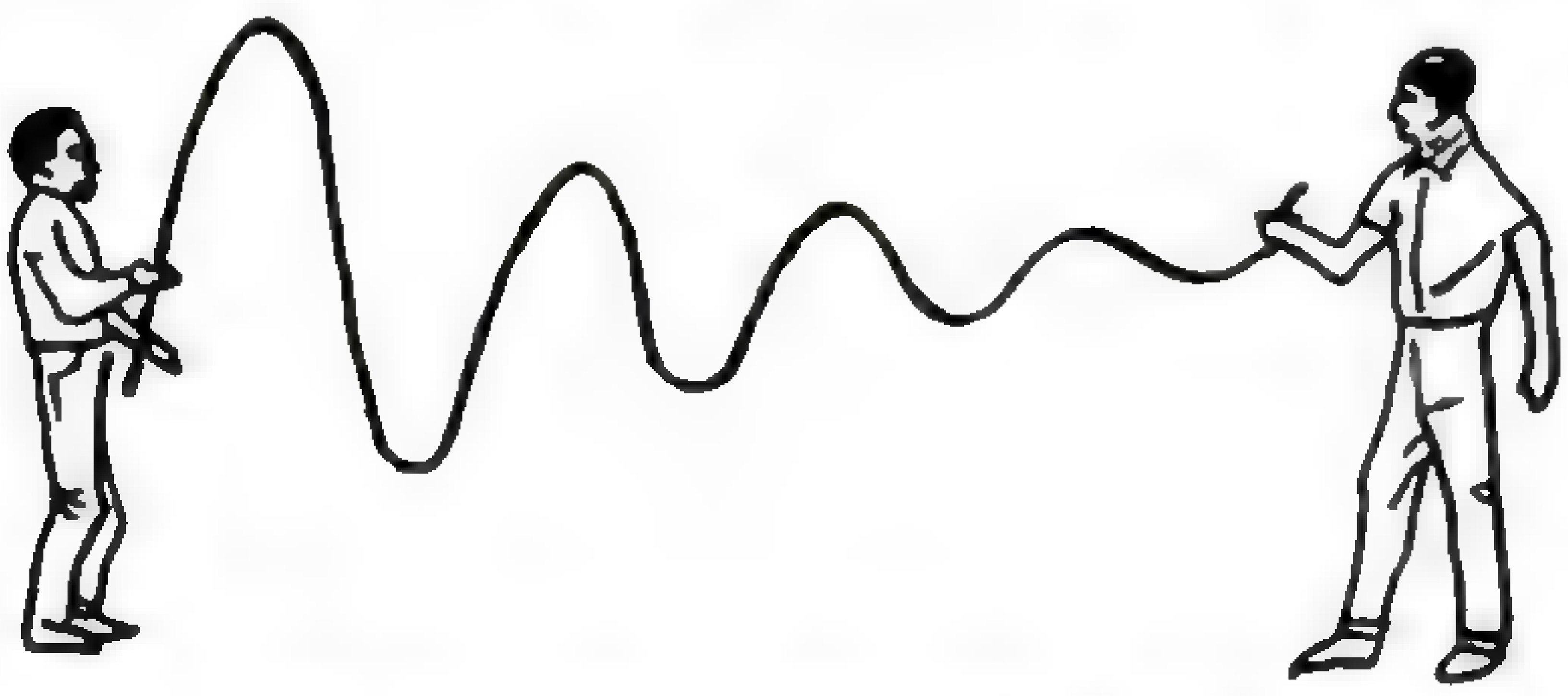
Q ***What is a laser?***

A The word LASER is an abbreviation for *L*ight *A*mplification by *S*timulated *E*mission of *R*adiation. In one form of laser, its key element is a synthetic ruby crystal, which performs the incredible feat of making all the light waves that emerge from it "march in step." Such "coherent" light can be bundled into a beam much narrower than that of the best searchlights.

Since light beams can be used just like radio waves to carry a voice, a command, or any other form of communication, a needle-sharp laser beam offers revolutionary advances in low-power communications across extremely large distances in space.

Q ***How does it work?***

A In the ruby crystal of the laser, impinging light energy from a lamp or other source can be stored temporarily,



by kicking orbital electrons of some of the crystal's atoms into higher orbits of temporary but limited stability. When the first electron thus "elevated" drops back into its original lower orbit, it emits a tiny package of light called a photon. A photon may be envisioned as a rapidly attenuated light wave, comparable to a wave tossed into a rope, as in my sketch above.

To understand this strange phenomenon better, consider the structure of an atom—any atom. In the simplest, the hydrogen atom, a single proton forms the nucleus and a single electron revolves around it. The nucleus of the oxygen atom consists of an array of eight protons and eight neutrons, around which revolve eight electrons in three distinct orbits. A chromium atom, found in a ruby crystal, has an even heavier nucleus with 24 orbiting electrons.

As an orbital electron absorbs the energy of an impinging photon, it will jump into a higher orbit whose energy level exceeds that of the original orbit by exactly the amount of energy that was brought in by the absorbed photon. The photon's energy, in turn, depends solely on the wavelength of the incoming light. However, in the atom of any given element, only certain specific transitions between orbits are "permissible," while all others are "prohibited."

Therefore the atoms of any particular element can absorb only photons of wavelengths that happen to be compatible with its own permissible set of electron orbits. When an "excited" electron—one that has been kicked into a higher orbit—falls back into the more-stable lower orbit, it emits a photon of precisely the same wavelength. (The fact that elements can emit only light of certain wavelengths becomes obvious when we look at the band spectrum emitted, for example, by a glowing neon tube.)

A ruby crystal is made up of chromium, aluminum, and oxygen atoms. Certain higher "excitation" orbits in the chromium atoms are "metastable," which means the electrons can stay quite a while in the higher orbits before they drop back. Thus the crystal does not

Laser Beams

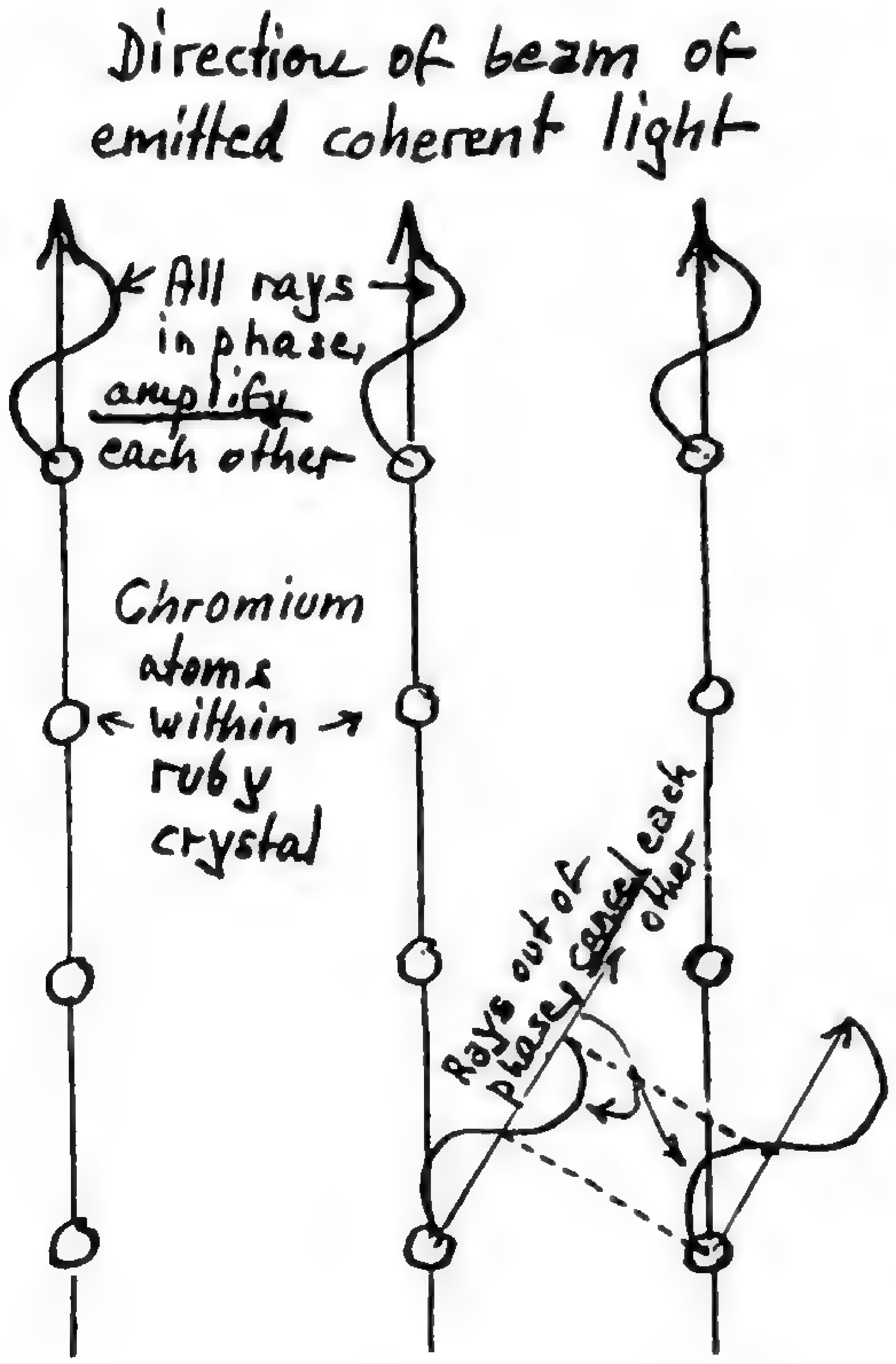
Dr. von Braun (left) holds an impromptu conference with Dr. Robert Gilruth, director of Manned Spacecraft Center at Houston, on air strip of Cape Kennedy's missile test area.

necessarily release photons at the same rate at which they are absorbed.

The ruby crystal can therefore be "pumped up" with quite a bit of light energy. However, once the first excited electron does drop back into the lower orbit—and emits its typical ruby-red light photon—the event virtually reverberates throughout the entire crystal. Every other excited electron likewise drops back and emits its photon.

The remarkable thing now is that, as the ruby dumps the stored energy, the light waves of all these emitted photons are precisely "in phase"; that is, the light emitted is "coherent."

Due to the physical size of the ruby crystal (which of course is many times larger than the wavelength of the emitted light), the emerging light waves do not arrive simultaneously at whatever target they hit. The situation can be best compared with a company of soldiers marching past a parade stand. While the first column passes the grandstand earlier than the last column, all the soldiers are marching in step.



Q *Why can a laser beam be bundled better than ordinary light?*

A The narrowness of the laser beam is a direct consequence of the crystal structure of the ruby. The bulk of the coherent light emitted (when the ruby dumps its stored energy) is beamed in the direction in which the chromium atoms are aligned within the crystal. This is simply due to the fact that, just as with monochromatic light passing through a grating, "interference" effects cancel much of the light emitted in other directions. (See my second sketch.) Narrowing down the laser beam is limited chiefly by the accuracy to which the ruby's exit plane can be manufactured. In practice, laser beams can be made about 20 to 30 times as sharp as the best searchlight beams.

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How Spacemen Can Use Laser Beams

[*Continued from page 129*]

Q ***How can a laser beam carry a voice or a signal?***

A In a laser communications system the ruby is irradiated with a suitable, continuous light source, and the crystal dumps its bursts into the needle-sharp beam at the rate of many thousand times per second. The distant receiver (at which the beam, of course, must be aimed with great precision) thus seems to see a practically continuous source of red ruby light.

To carry a voice, a suitable light filter is inserted into the beam. Its filtering effect is modulated, or varied, with the electric current from a telephone mike. At the receiving end, the varying intensity of the impinging light beam is used to produce the current that drives the loudspeaker.

Q ***What else can a laser do?***

A It has been suggested to use the laser principle to generate "death rays" capable of killing soldiers at a distance of several miles, or of destroying missiles or airplanes in the sky.

Any such use of the laser principle, of course, would call for a laser that could produce tremendous power surges of the order of thousands or even millions of kilowatts. In a ruby crystal the bulk of the absorbed energy is converted into useless heat, and only a small percentage is utilized for the production of the beamed surges of coherent light. As long as we are dealing with the relatively low power levels required for communications, the resulting cooling problems can be mastered. However, if we try to produce surges capable of destroying an airplane miles away, the much greater heat development within the laser system itself is liable to destroy the crystal.

Nevertheless, there is much research going on in this field, and many people believe that the laser has great potential as a future weapon. ■ ■

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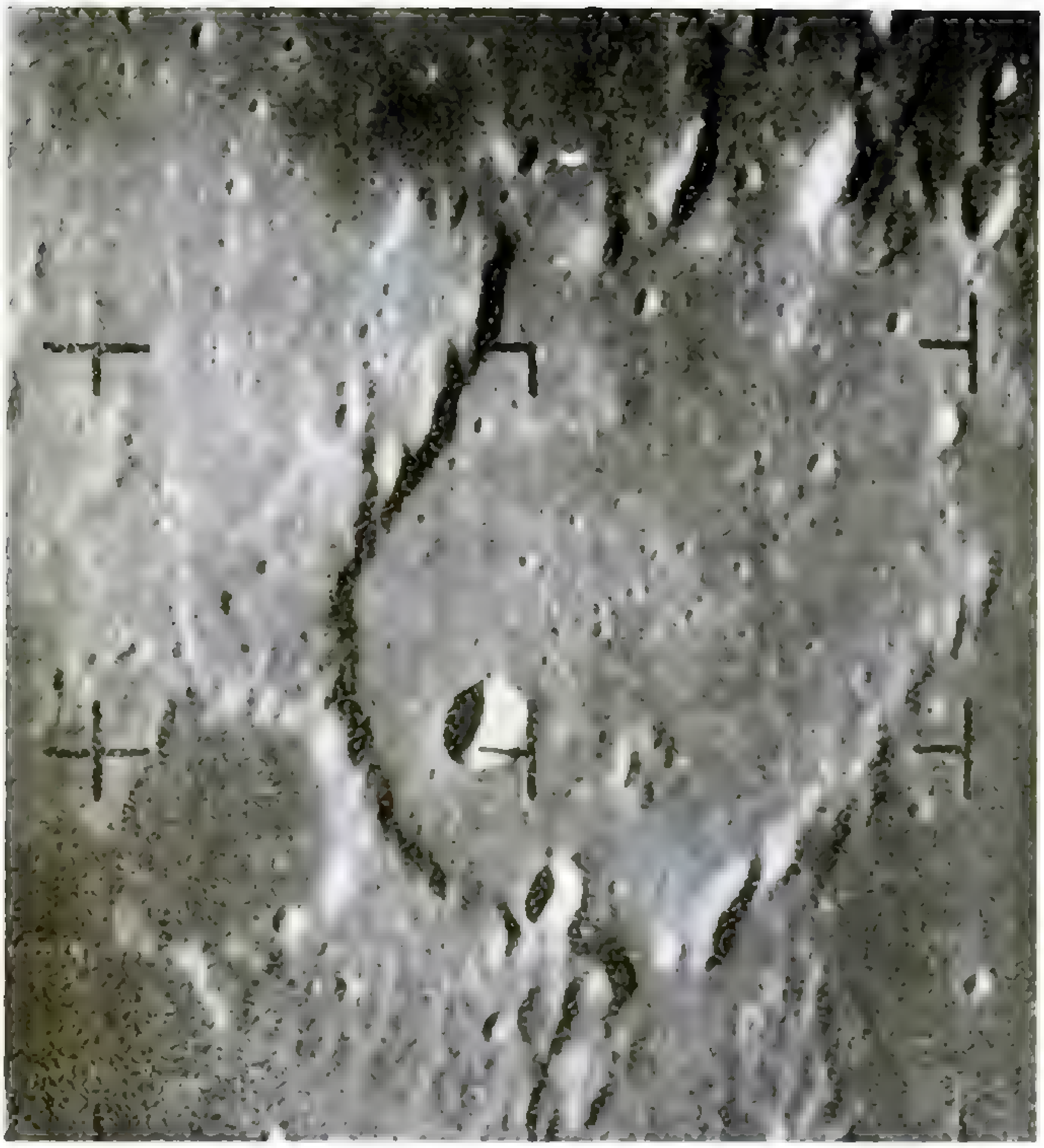
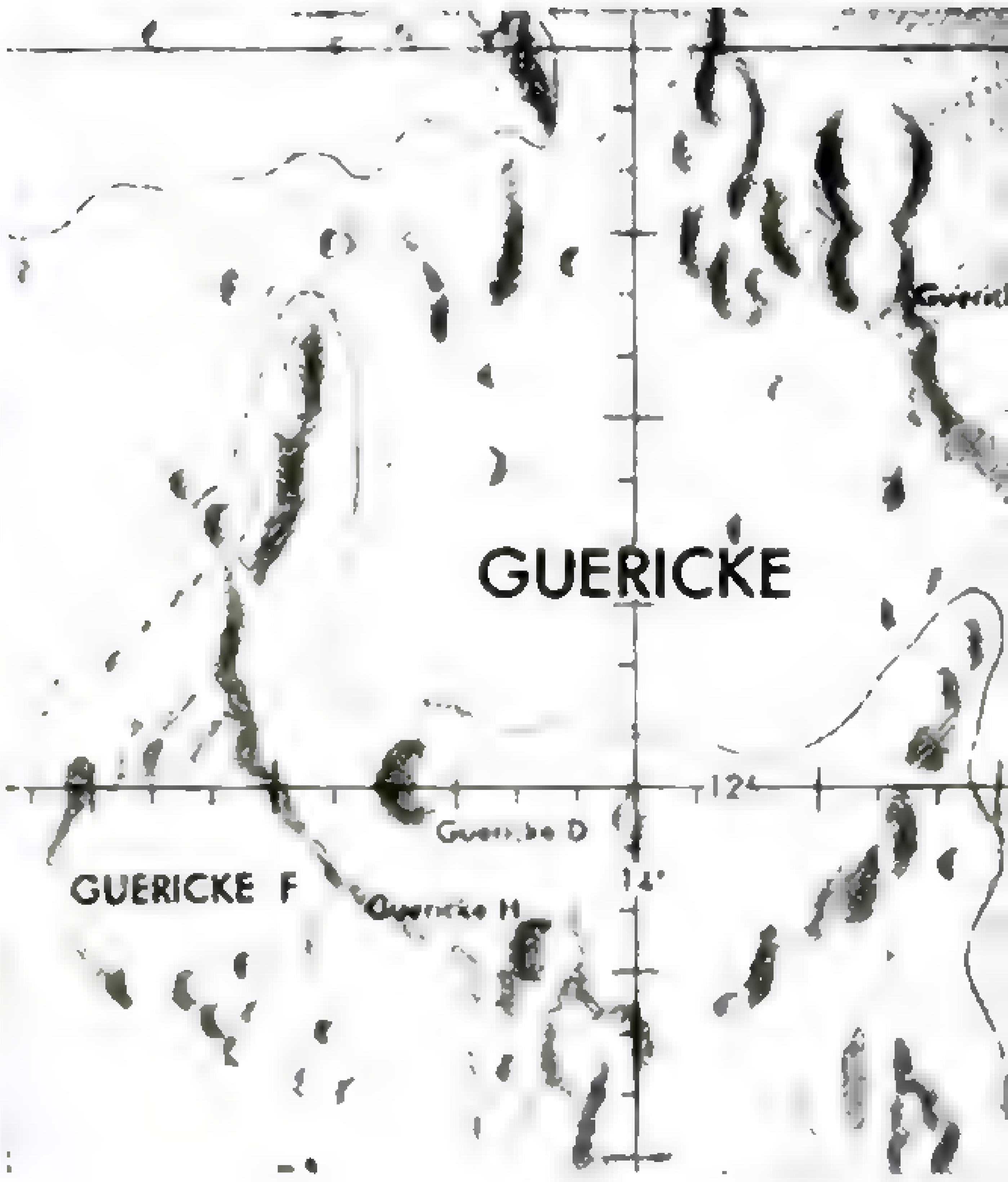




"Beautiful," astronomers call Ranger photo, left, of crater Guericke from 470 miles away. It reveals details 10 times as small as on photos from earth, from which Air Force lunar map above was made. As Ranger whizzed closer to moon, views showed far more that was new.

By
Wernher von Braun

Because of the Ranger pictures' importance to the Apollo program, we asked Dr. von Braun to tell what they show. His usual Question-Answer column will be resumed next month

LAST July 31 at 6:25:49 a.m. Pacific Daylight Time, the Ranger 7 spacecraft impacted on the moon, about halfway between the Guericke and Lubiniezky craters, after radioing 4,316 pictures back to earth. So much did they tell, that the hitherto nameless region where Ranger 7 crashed has since been named Mare Cognitum (Known Sea).

The pictures were taken with two wide-angle and four narrow-angle television cameras, developed for NASA's Jet Propulsion Laboratory by the Radio Corporation of America. Picture-taking began 18 minutes prior to impact, at an altitude of 1,300 miles, and ended with the destruction of the spacecraft

Change Our Plans?

on the lunar surface. The last picture was taken from 1,000-foot altitude and covered a 60-by-100-foot area. Its resolution was adequate to show objects on the lunar surface only 1½ feet across.

While it will probably take months or years to extract all scientific information of interest from the pictures, it is not too early to draw some important conclusions as to the feasibility of Project Apollo—NASA's program to land two Americans on the moon before the end of the decade.

The gist of it all: The pictures from Ranger 7 have given our confidence in a successful lunar landing a tremendous boost.

Certainly, the long flight of an Apollo spacecraft from earth to moon and back is fraught with all kinds of difficulties and hazards. Along with its Saturn V boost rocket, the spacecraft requires prowerful and reliable rocket engines, a sophisticated structural design, complex trajectory calculations, and extremely precise guidance and navigation equipment. Success of the mission depends also on training the astronauts in things ranging all the way from celestial mechanics and simulator runs to the art of cooking lizards as part of desert-survival techniques.

PS shows how moon might look to astronauts approaching it by inserting Ranger photo, from 34-mile height, in photo of landing-craft mock-up. (The actual view, of course, would vary with the craft's attitude.)

But there had always been one aspect of Project Apollo that had stubbornly defied all attempts at scientific investigation and better understanding:

What was the moon's surface really like? Was it covered with boulders and debris that would make a touchdown on the spidery landing legs of the Lunar Excursion Module hazardous or impossible? Was the lunar surface covered with dust—and if so, how deeply? Would the surface have enough bearing strength to support the spacecraft's weight? Would it support an astronaut walking on it—or a vehicle running on it?

The answers were so elusive because the most powerful astronomical telescopes, hampered by the turbulence of the earth's atmosphere, could distinguish nothing smaller than a mile across on the lunar surface. They are elusive no longer because the best close-up pictures

CONTINUED

from Ranger 7 have improved this resolution by about 2,000 times.

The big look. The first appraisal of the pictures was conducted by Dr. Gerard P. Kuiper, eminent Dutch-born lunar and planetary astronomer of the University of Arizona, and Dr. Eugene Shoemaker, famous geologist of the Institute of Astro-Geology in Flagstaff (under contract to NASA to help evaluate lunar-surface exploration methods), whose main interest is the topography and structure of the lunar surface. Their findings can be summarized as follows:

- The Ranger 7 pictures show no evidence of deep layers of loose dust. On the contrary, the moon's surface looks to be pretty hard.
- The present design of the Lunar Excursion Module for the Apollo project is entirely adequate to land on terrain such as was impacted by Ranger 7. There is no need for any redesign of the Module or its landing gear.
- There is no need to abandon the old theory that lunar craters have been produced over millions of years by the impact of meteorites, ranging in size from a city block down to a grain of salt.

Rock lying in crater made by its impact proves lunar surface is firm. Striking photo was from a height of only three miles.

- Ranger 7's pictures clearly show that the pattern of the tiny, hitherto invisible craters is not fundamentally different from the bigger ones. There are simply more of them. Observations on the statistical distribution of brighter and dimmer shooting stars in the earth's atmosphere are in full agreement with this finding.
- Besides the craters and craterlets formed by "direct" hits, there are many "secondary" craters formed by rocks hurled away by meteorite impacts. The pictures indicate that these secondary craters tend to be grouped in clusters.
- Black shadows in one secondary crater seen by Ranger 7 are cast by a large jagged rock that came to rest within the crater's rim—obvious proof that the bearing strength of the lunar surface must be considerable
- Conspicuous "rays" emanating from some of the "younger" craters such as Copernicus and Kepler are not, as had previously been surmised, made of some fluffy stuff. One older theory held that some powdery light-colored material had been tossed out of the moon's interior by the impacting meteorite. Another theory suggested that the rays were formed by volcanic gases, oozing out of the wound made by the meteorite, that subsequently froze in the cold lunar night on the darker ground beneath.

Drs. Kuiper and Shoemaker believe the Ranger pictures indicate that the rays should rather be looked upon as alleys of rocks and secondary craters, along which most of the debris was hurled out by the impacting meteorite.

They conclude that the rays constitute rough areas particularly unsuited for safe landings. But even in a ray area, they feel, smooth landing sites big enough to accommodate a Lunar Excursion Module may be found.

Both Dr. Kuiper and Dr. Shoemaker, in discussing the Ranger 7 pictures' significance, repeatedly stated that scientists should not be expected to make any

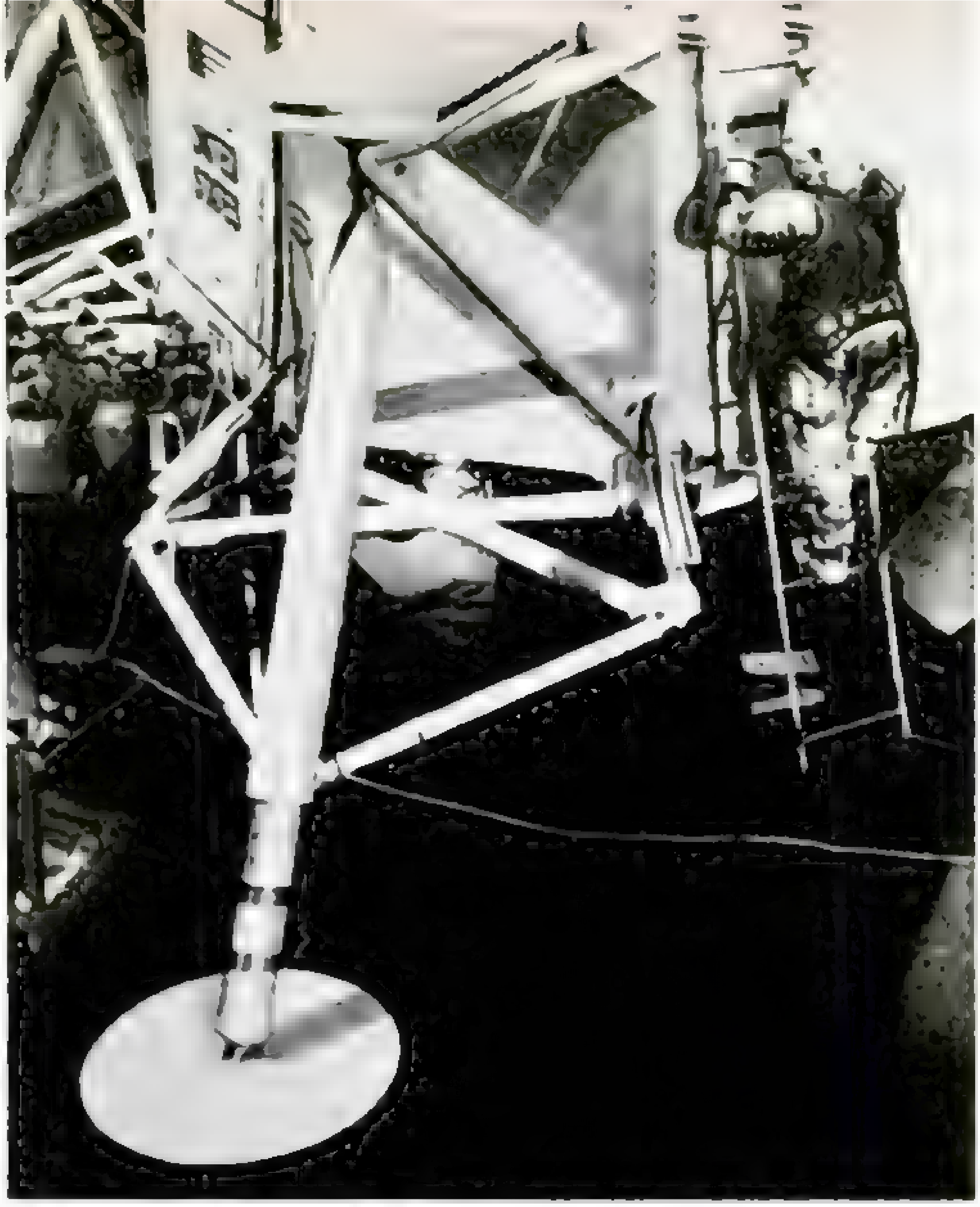
rash statements and evaluations in the face of a sudden windfall of unprecedented observations. Nevertheless, for all their guardedness, they saw fit to make the above statements without qualification. As an engineer, I can only add that on any terrain suitable for a touchdown by an Apollo LEM, an astronaut can walk and a lunar surface vehicle can operate.

To some, Ranger 7's last pictures—though probably the most significant—may seem lacking in spectacular detail. If the moon is so dull-looking a place, is it really worth visiting? Of course the answer is that Ranger 7 was carefully aimed at an impact area in one of the dark, flat lunar plateaus (called mares because the ancients thought they were seas) that from the outset had been considered most suitable for a touchdown by the Lunar Excursion Module. Many other areas promise far more spectacular scenery or scientific mystery.

The Straight Wall. Less than 150 miles from where Ranger 7 fell is the wall—a tremendous cliff 60 miles long, more than 800 feet high, steeper than the Palisades of the Hudson River. There are mighty mountain ranges. There is the entire central area of the moon's southern hemisphere, virtually covered for some unknown reason with craters of all sizes—craters that overlap, even craters within craters.

Then there is the crater Kepler, center of a major ray system and one of the most conspicuous objects on the moon. Kepler and its walls and rays are undoubtedly one of the most rugged lunar areas, but one of the most intriguing research objects for a landing party. What pictures would another Ranger get if it were to descend into this crater, 22 miles in diameter and no less than 10,000 feet deep? What but another unmanned spacecraft can tell if a manned landing on the bottom is possible.

For the time being, however, Apollo must limit its ambitions and aims to



Disk-footed landing gear of Lunar Excursion Module is okayed by moon photos. Planned ability to alight safely on rough surface at tilt up to 15 degrees from vertical is shown adequate.

less-difficult landing sites. It is likely that the next Ranger again will try to get good close-up pictures of a lunar mare—just to make sure that Ranger 7's pictures of Mare Cognitum are truly representative of any mare.

Our present appraisal of the lunar surface's nature and its suitability for a landing may be summarized this way:

The surface is made up of some porous, rocklike material—whose exact chemical composition is unknown, and is even likely to vary between distant locations. Its porous nature results from incessant bombardment by tiny micrometeorites.

It appears likely that this hail of micrometeorites is even less dense on the moon than in a near-earth orbit, where we have no evidence that it ever endangered an astronaut or wrecked an unmanned spacecraft. However, the moon lacks a protective atmosphere like the earth's, and this bombardment has been going on for millions of years. This has created an extremely slow-acting, feature-changing force on the moon that might be called "meteorite erosion."

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Do the Moon Photos Change Our Plans?

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Whenever every 10,000 years or so a big meteorite throws up a big lunar crater—say, the size of our Meteor Crater in Arizona—the crater itself and the material splashed out look fresh for a while. The crater has a steep rim. A bright system of rays shows in which directions debris has been hurled. But the constant hail of small meteorites gradually erodes away the sharp features. Many old craters have no ray system. Some, in or near mares, look as if they were slowly filling up with dust.

No dust on the moon? Many people, including myself, have always held that there cannot be much loose dust on the moon—even though micrometeorites are incessantly kicking up some dust by splashing particles out of the rock they hit. A simple experiment shows that dust in a vacuum, as on the moon, becomes hard-packed. In fact, without any atmospheric oxygen around that could produce a contact-preventing oxide coating, "cold welding" of adjacent dust particles will fuse them together into a pumice-like substance.

The bearing strength of such a fused, porous material is hard to predict. Even Ranger 7 has not provided a complete and generally valid answer. Nevertheless, the qualities of snow offer a good illustration of what to expect:

Snow comes in various densities—from fresh-fallen "powder" snow, to the frozen-over, melted-down snow called "firn." But all types of snow have in common the feature that, as you step on it, you sink in only until it is compressed enough to support your weight. While some powder snow may be too soft to walk on comfortably, all types of snow can at least be negotiated with skis or tracked vehicles.

There is reason to believe, however, that most of the moon's surface is substantially harder than soft powder snow. I think a man walking on a lunar mare will make a visible footprint, and he may hear a crunchy noise. But since his weight is reduced to one-sixth of his earth weight, he'll have no trouble walking. ■ ■

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TRUE ADVENTURE:

The Flight the Navy Can't Explain

Dr. Wernher von Braun explains:

How Propellants Are Fed to Liquid-Rocket

Q ***How are the propellants fed into a liquid-rocket engine?***

A Two basically different methods are in use: pressure feeding and pump feeding.

Pressure feeding is simple, but relatively heavy. Pump feeding offers a very substantial weight advantage, at the price of greater complexity.

Q ***What is pressure feeding?***

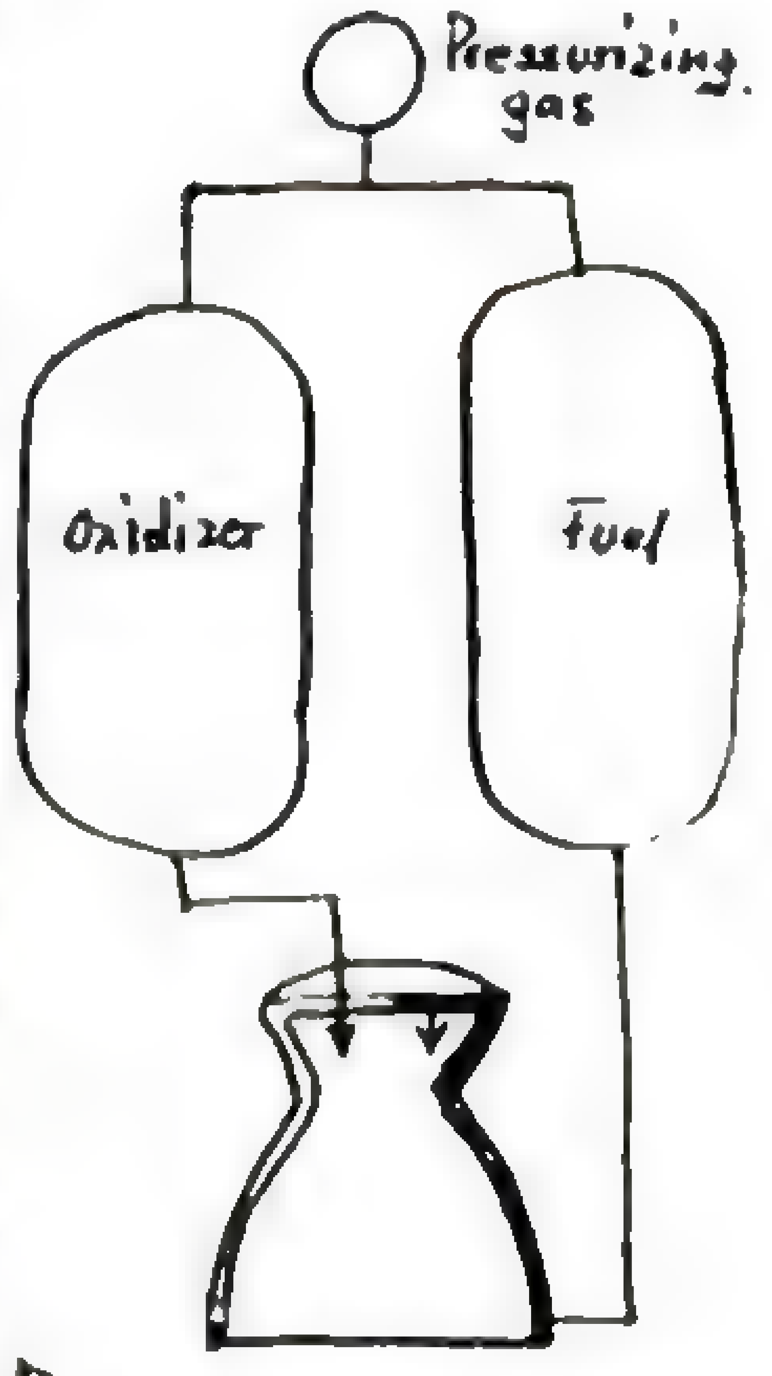
A In a pressure-fed rocket-propulsion system, the fuel and oxidizer tanks are pressurized, to a level sufficient to feed the propellants directly into the combustion chamber.

For efficiency, the combustion-chamber pressure must be pretty high—and the feed pressures obviously must be still higher. Thus pressure-fed rockets require strong and heavy propellant tanks.

The main advantage of pressure feeding is simplicity. The inherent weight disadvantage becomes less noticeable in some rockets, such as air-defense missiles. Due to their high accelerations, and aerodynamic loads caused by maneuvering within the atmosphere, these rockets are subjected to high structural loads. The tanks that form their structure must be strong, anyhow.

The pressurizing gas for a pressure-fed rocket may simply be taken along in high-pressure containers. To save weight, some rockets carry the pressurizing gas in liquefied form. The liquid is converted into a gas either by heating it in a heat exchanger, or by chemical decomposition.

In the latter case the liquid must be a "monopropellant." This is a chemical that decomposes into its components, and simultaneously releases heat, on contact with a suitable catalyst. Hydrogen peroxide (H_2O_2), a water-like liquid, decomposes into a mixture of steam (H_2O) and oxygen (O_2) when forced through a catalyst bed of calcium permanganate. Another monopropellant, hydrazine (N_2H_4), which is likewise liquid at room temperature, decomposes on contact with a catalyst into a mixture of hot nitrogen (N_2) and hydrogen (H_2) gases.



Pressure-fed system

Solid propellants are rarely used to generate pressurizing gas for pressure-fed liquid rockets, since all of them produce quantities of solid particles in the gas, which may clog valves or regulators and may also be corrosive.

My sketch at right shows the principle of a typical pressure-fed liquid rocket.

Q ***What about pump feeding?***

A Because of the substantial weight advantage, virtually all high-performance liquid-propellant rockets use pump feeding. It permits using thin lightweight propellant containers in combination with highly efficient high-pressure rocket engines.

There are always two separate pumps—one for the fuel, the other for the oxidizer. Most common are centrifugal pumps, not too different in basic design from the water pumps used in fire engines. For liquid hydrogen, however, multibladed axial pumps are often used. Their rotors look a bit like the compressors of turbojet engines.

The propellant pumps of all liquid rockets are powered by gas turbines. Some-

Dr. von Braun, right, is pictured in his office as he chatted last year with Charles H. Percy, chairman of the board of Bell & Howell Company.

Engines

times the pumps are mounted on a common shaft, with the drive turbine either between the two pumps or on one end. Sometimes the high-r.p.m. turbine is connected to the slower-spinning pumps via a gear train. In some rocket engines the pumps are separate each with its own turbine.

Q ***What drives the pumps' turbines?***

A The turbines are always driven by expansion of hot high-pressure gas through their blades. But many different methods have been developed to generate the drive gas, as shown in my sketch at right.

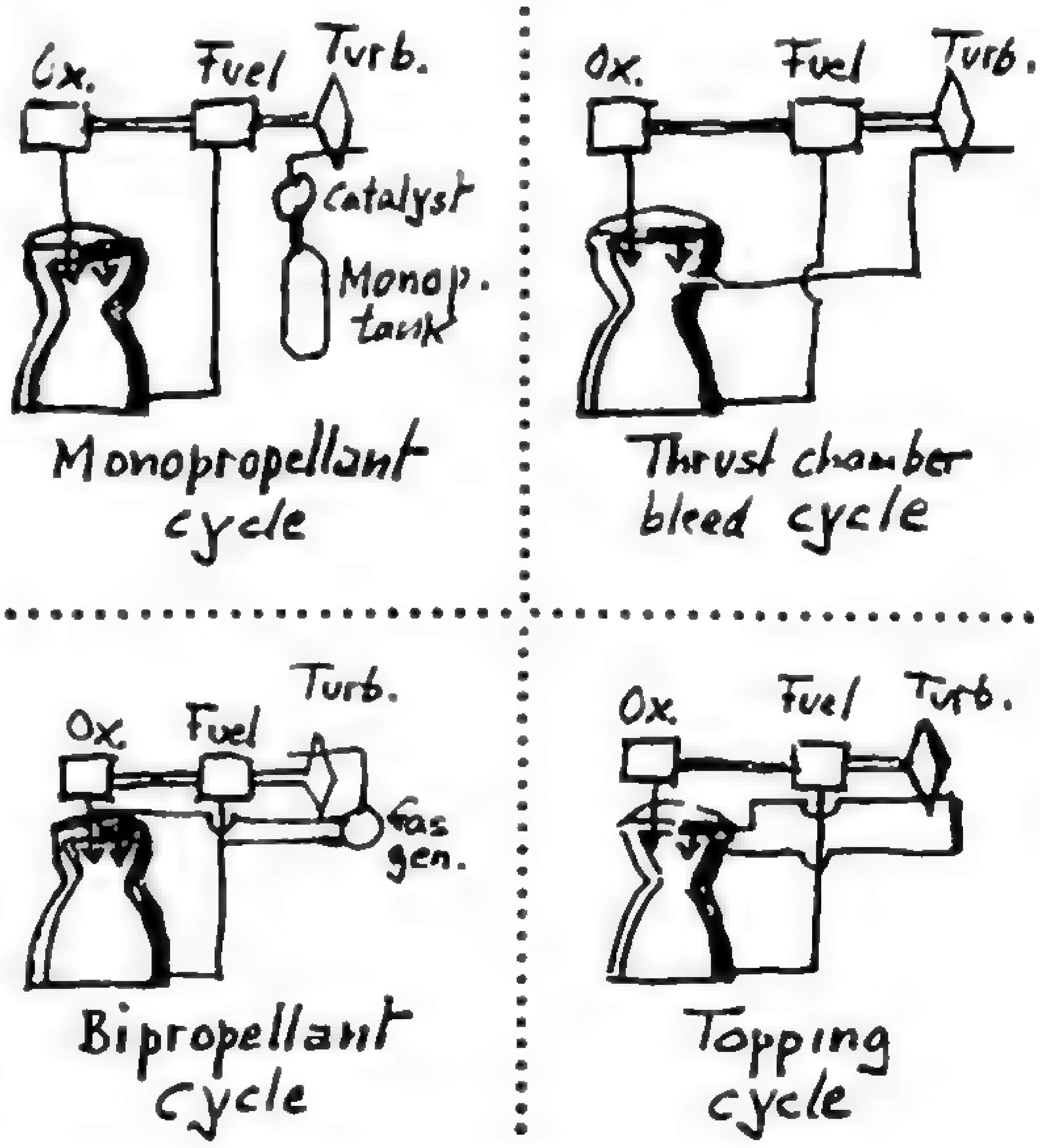
Early liquid rockets, such as the V-2, Viking, and Redstone, used a *monopropellant* gas source and carried a separate hydrogen peroxide container. From this relatively small tank, the peroxide was pressure-fed into a catalytic decomposition chamber. Steam and oxygen emerging from this chamber drove the turbine.

Most modern liquid-rocket engines use *bi-propellant* gas generators. Oxidizer and fuel are tapped off the high-pressure discharge lines of their respective pumps and are fed into a gas generator. This is a high-pressure furnace in which the propellants burn—usually at a rather fuel-rich mixture ratio, to keep the gas temperature low enough for the turbine blades.

In the 200,000-pound-thrust Rocketdyne J-2 engine—the liquid-hydrogen/liquid-oxygen engine that will power the second and third stages of the Saturn V moon rocket—the hydrogen-rich combustion gas emerging from the gas generator first drives the turbine of the liquid-hydrogen pump. Still rather hot and under moderate pressure, the gas is then ducted to the opposite side of the engine, where its further expansion drives the turbine of the liquid-oxygen pump. Through a large wraparound manifold, the cooled-off drive gas is finally admitted to the rocket's main exhaust nozzle, where it augments the thrust.

Of course, only a minute fraction of the fuel and oxidizer is tapped off into the gas generator. The bulk flows into the main combustion chamber.

Instead of producing the turbine drive gas in a separate gas generator, it has been repeatedly attempted to bleed the gas directly off the main combustion chamber.



While this *thrust-chamber bleed cycle* looks at first blush like a very obvious solution, it is actually beset with two major difficulties. For one, the combustion gas bled off the main chamber is too hot to be admitted directly to the turbine. It must be cooled by injection of water or additional fuel. Secondly, it is quite difficult to control the power level of the turbine with sufficient

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accuracy, because the heat energy of the drive gas is greatly dependent upon the local gas condition in the chamber near the bleed-off point.

The so-called *topping cycle* provides the best turbine-drive system from the viewpoint of overall economy. This cycle is used in the Pratt & Whitney RL-10 hydrogen-oxygen engine, six of which power the second stage of the Saturn I rocket.

In the topping cycle, the liquid hydrogen is pumped through the cooling jacket of the main combustion chamber, where it picks up enough heat from the warm metal to evaporate. Led through the turbine, the expanding gas spins it. The expanded hydrogen is then admitted to the combustion chamber, where it burns with the oxygen that has been pumped in separately.

Q ***How are pump-fed engines started?***

A The older pump-fed rockets, using a monopropellant gas generator, were started by first establishing a small gravity-fed flow of fuel and oxidizer into the combustion chamber, and igniting it. Then the hydrogen peroxide valve was opened, admitting the pressure-fed stream of monopropellant to the catalyst bed. The vapor emerging from the gas generator whipped the turbine up to speed, and the rocket took off.

Rocket engines with bi-propellant gas generators are usually started with pyrotechnic "spinners." A little solid-propellant "rocket" shoots a fire stream simultaneously into the turbine blades and into the gas generator. Ignition of fuel and oxidizer entering the gas generator is provided by the spinner flame. After the spinner extinguishes, the pumps keep running.

Topping-cycle engines burning liquid hydrogen are the easiest to start. One simply opens a valve, allowing liquid hydrogen to flow by gravity into the warm cooling jacket. As the cold liquid absorbs heat and evaporates, the expanding gas starts to spin the turbopump. This increases the flow rate of the liquid hydrogen into the cooling jacket—which, in turn, further increases the gas flow through the turbine.

The topping cycle thus takes ingenious advantage of the allegedly hard-to-handle "cryogenic" fuels (low-boiling liquefied gases such as liquid hydrogen): It uses the temperature difference between the room-temperature engine metal and the cold propellant to start the engine.

Q ***Can pump-fed engines be throttled?***

A Yes, quite easily. It's done by throttling the r.p.m. of the turbopump.

With monopropellant gas generators, one simply throttles the flow of monopropellant to the catalyst bed. The resulting r.p.m drop of the turbine reduces the flow rates of fuel and oxidizer and, thus, the combustion pressure and engine thrust.

In a bi-propellant system, the same effect is obtained by throttling the flows of both propellants into the gas generator.

The hydrogen-oxygen topping-cycle engine is throttled by increasing a variable percentage of hydrogen, emerging from the cooling jacket, that is allowed to bypass the turbine and enter the thrust chamber directly. Likewise, a drop in turbine r.p.m. results.

Q ***How is mixture ratio controlled?***

A This is indeed a critical problem, particularly with large and highly efficient liquid-rocket systems. Obviously, all advantages gained by ultra-light structural design could easily be lost if the control of the mixture ratio was so poor that thousands of pounds of useless oxygen were left in the rocket's tanks when the fuel was used up.

Modern large liquid rockets often have "capacity probes," inserted in the fuel and oxizider tanks, that indicate at every moment how much there is left in each tank. This information is fed into a simple computer that controls a throttle or bypass valve in either the fuel or the oxidizer system. The throttle valve then sees to it that both propellants are depleted simultaneously. Such "propellant-utilization systems" even permit rocket engines to be operated at varying mixture ratios during flight—which turns out to be advantageous for squeezing maximum payload performance out of a rocket of given design. ■ ■

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WAS JOHN GLENN ... CE?

America's leading rocket expert takes you behind the scenes to explain what happens when a big space vehicle like the Saturn is launched

WHY AND HOW OF THE COUNTDOWN

By Dr. Wernher von Braun

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

TO THE average TV viewer, the countdown of a big rocket is a curious space-age fad. A set of numbers flicking on the screen and a studiously unemotional voice team up in the strange ritual of counting seconds backward. Obviously invented by a showman, its sole purpose seems to be to build up tension and excitement for the audience. As the clock at last strikes zero, the show culminates in the fiery spectacle of the launch.

Probably few laymen know the real purpose of a countdown, or just how one is carried out. Actually a countdown is a carefully developed procedure of preparation for launch. Because of its tremendous importance to the success of a rocket firing, its details deserve to be better understood.

What countdowns are for. The purpose of a countdown is to:

- Assure maximum safety for flight crews (if any), ground crews, and equipment, while the vehicle is prepared for flight.
- Avoid wearing out critical flight or ground equipment by activating it too long before launch.
- Enable the launch director to launch at an exact instant—corresponding, say, to a favorable position of celestial objects, or to requirements for orbital rendezvous.
- Synchronize launch preparations with supporting operations such as the readying of radars and tracking cameras, or the setting up of road blocks near the launch site.

For operational military rockets, the response to a firing order must be quick. Little if any telemetry for collecting data in flight is involved. Such a countdown may take only a few minutes.

But a complex multistage rocket carrying an equally complex spacecraft and highly sensitive research gear, whether unmanned or with a human crew, requires a countdown that may extend over many hours.

In case of trouble. If the countdown goes according to plan, it's pretty rigid, but it offers plenty of flexibility if difficulties arise. Essential to a well-prepared countdown plan is a set, clear-cut procedure for "recycling the count."

Suppose an equipment malfunction occurs, after much of the on-board guidance and radio equipment has been turned on—and an estimated two hours will be required to repair or replace the faulty part. Obviously much of the activated on-board gear should be turned off again. Therefore the countdown—already advanced, say, to T minus 7 minutes—may be cycled back to "T minus 20 and holding." This means that

In Cape Kennedy blockhouse, Dr. Kurt H. Debus (lower center) directs countdown for a Saturn launching. Dr. von Braun (arrow) watches at periscope. Black block on control panel (foreground) is official countdown clock.

the count will be resumed at T minus 20 minutes, whenever the repair work has been completed and the replacement part has checked out okay.

But there may be merely a temporary radio interference, clearly traced to a passing aircraft. In this case the count will be held "momentarily." No equipment will be turned off. The count will continue at the clock reading where it was stopped, as soon as the trouble clears up.

A set of emergency procedures, in a well-planned countdown, safeguards flight and ground crews and the space vehicle in the event of any serious malfunction. The proper emergency procedure must vary as the countdown clock ticks along. It undergoes drastic changes as hazardous fuel and oxidizer are pumped into a liquid rocket's tanks; again, as the servicing structure is removed from the space vehicle, and there is no longer access to certain critical stations of the vehicle. A few minutes later, after ground crews have evacuated the launch-pad area, the flight crew monopolizes the launch director's concern for safety of personnel. In case of a dangerous fire in the rocket, for example, the crew of the spacecraft may now fire its escape rocket without endangering the ground crew.

In the final phases of the countdown the text for the emergency procedures, usually printed on every back page of the countdown book, becomes longer than that for the actual launch procedures themselves.

How SA-7 was launched. The Cape procedures for SA-7, our seventh Saturn I rocket, launched last September 18 from the John F. Kennedy Space Center in Florida, illustrate the launch preparations and the countdown of a large rocket still in the developmental stage.

It was at Cape Kennedy that the elements of this two-stage Saturn rocket had first met. The eight-engine first stage, assembled and static-tested at NASA's George C. Marshall Space Flight Center, had come to the Cape by barge. The hydrogen-oxygen powered six-engine second stage, static-tested at Sacramento, Calif., by its maker, the Douglas Aircraft Co., had arrived by air. From Marshall, again, had come the "instrument unit," a ring segment carrying all of the rocket's guidance and most of its radio equipment. The "boilerplate Apollo"—

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Why and How of the Countdown

[Continued from page 67]

an unmanned, instrument-filled mockup of the Apollo spacecraft—had been flown in from the Los Angeles plant of the manufacturer, North American Aviation, Inc. Additional parts had come from NASA's Manned Spacecraft Center in Houston.

After a receiving inspection, a few days' hangar delay for "updating" (substitution of improved parts arriving belatedly by special messenger), and further checkout of "individual" and "integrated" systems, the elements of SA-7 went to the launch pad.

The first stage was erected on the platform. The second stage was piled on top of it. The small but complex instrument unit was added to the stack. Finally the Apollo spacecraft was mated to the rocket. A careful alignment check followed.

Then SA-7 was connected to the "umbilical tower." This open-grid steel structure, taller than the rocket itself, supports the "swing arms" that connect a rocket electrically, pneumatically, and hydraulically with its ground-support equipment. They disconnect and swing out of the way as the rocket begins to rise from the launch pad.

Now came many days of checking out the vehicle and its ground-support equipment together, including tests of automatic fueling procedures; on-board tracking beacons and ground tracking stations; launch vehicle-spacecraft compatibility; and radio interference. Finally an integrated "Overall Test" showed that the entire complex of flight and ground hardware was ready.

The countdown. Six hours prior to the planned launch time of 10:00 a.m., the countdown began.

First came installation or activation of the vehicle's "ordnance"—which stands for anything in it that can be ignited with a pyrotechnic fuse. In SA-7 the work of the ordnance crew included the installation of:

- The ignition device of the Apollo spacecraft's escape rocket.
- Initiators of explosive bolts to release the spacecraft's escape tower, and to separate the second stage from the first.
- Initiators of explosive "cutting charges" to open the vent ports prior to ignition of the second stage.
- Destruct charges to destroy the vehicle in midair, in case of an erratic flight.

This job, with checks of electrical connections and circuits, took about three hours.

At T minus 3 hours, the liquid-oxygen

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tanks were filled, in the second and first stages in turn. (The kerosene tanks of the first stage had been filled days earlier.)

At T minus 2:30, the hatch to the Apollo spacecraft was closed and the service gantry was pulled back. Half an hour later, the launch pad was cleared of all personnel, and automatic liquid-oxygen and liquid-hydrogen "topping" systems that make up for evaporation losses were activated.

At T minus 45 minutes, the first-stage fuel tanks were pressurized. Various nitrogen purge lines were turned on to prevent combustible gas mixtures, caused by possible leaks, from accumulating in the craft.

At T minus 25 minutes, the environmental control system in the spacecraft was activated. Five minutes later, all spacecraft electronic systems were turned on—telemetry, tracking beacons, and so on.

Four minutes before launch, all electrical systems were transferred from external (ground) power to internal (on-board) power, and all electrical "bus" lines feeding into the ordnance systems were armed.

At T minus 2 minutes and 30 seconds, the "firing command" was given that transferred all further duties of setting systems in operation to an automatic sequencer. From this point on, the launch director and his assistants merely monitored the automatic sequence, ready to interrupt it at the slightest sign of trouble. The automatic-sequencing mechanism, however, has a rather intricate interlocking system that releases each step in the sequence only after the previous one has been correctly executed.

At T minus zero, the eight engines of the first stage were ignited. One second later, the umbilical swing arms disconnected and moved out of the way. The hold-down devices released at T plus 2 seconds—and SA-7 was on its way.

So there you have the why and how of the countdown. As you have seen, it is no space-age fad, but a deadly serious, carefully programed procedure, upon which depend the safety and success of a launch such as that of a great Saturn rocket. ■ ■

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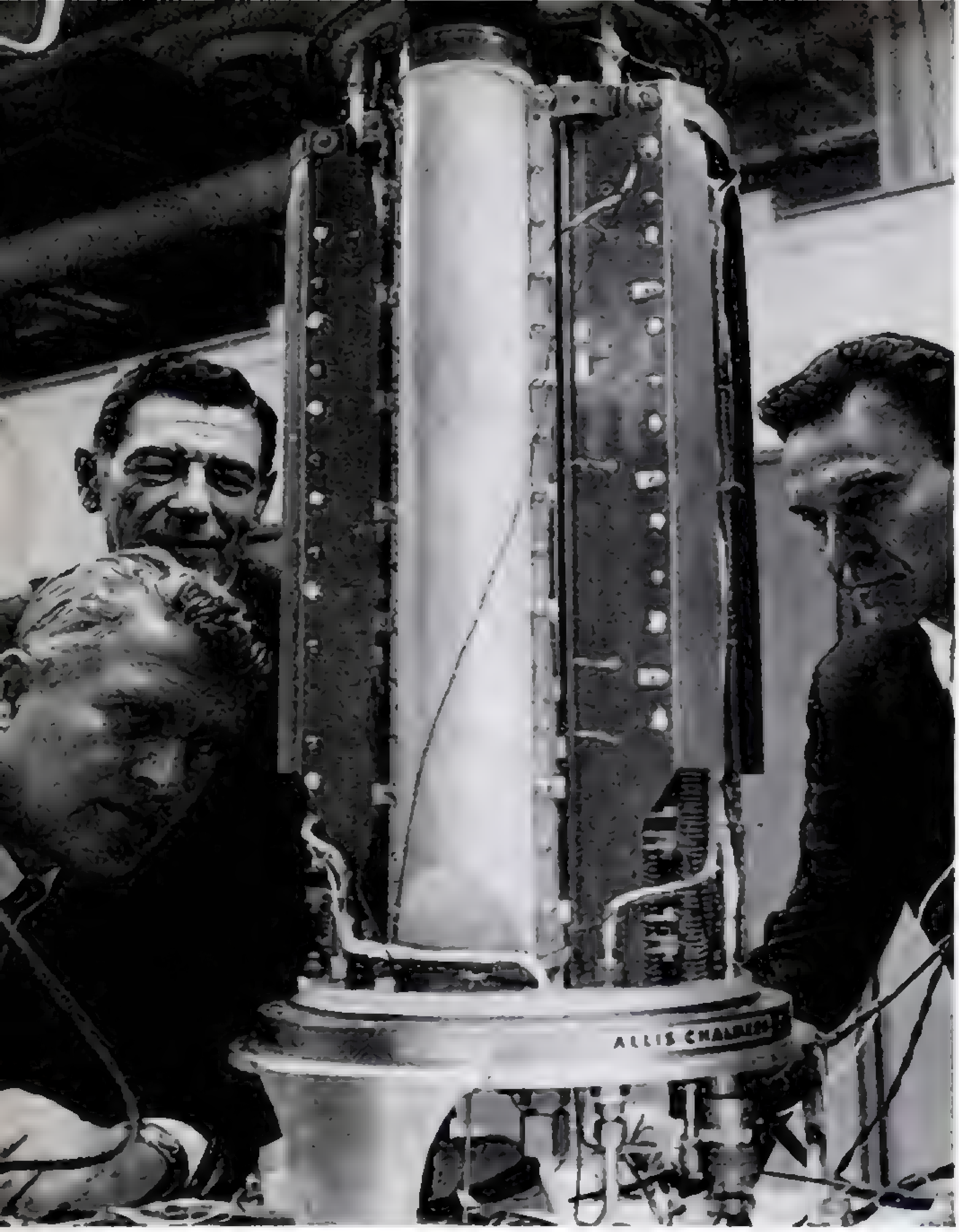


Dr. von Braun, left, inspects new fuel cell for space vehicles. It turns hydrogen and oxygen into 2,000 watts of electricity, plus pure drinking water for astronauts.

So far, from Mercury to Apollo, our program of manned space flight has bypassed a pioneer idea for living in space. Here a noted authority answers the question:

What ever happened to the Manned

By Dr. Wernher von Braun

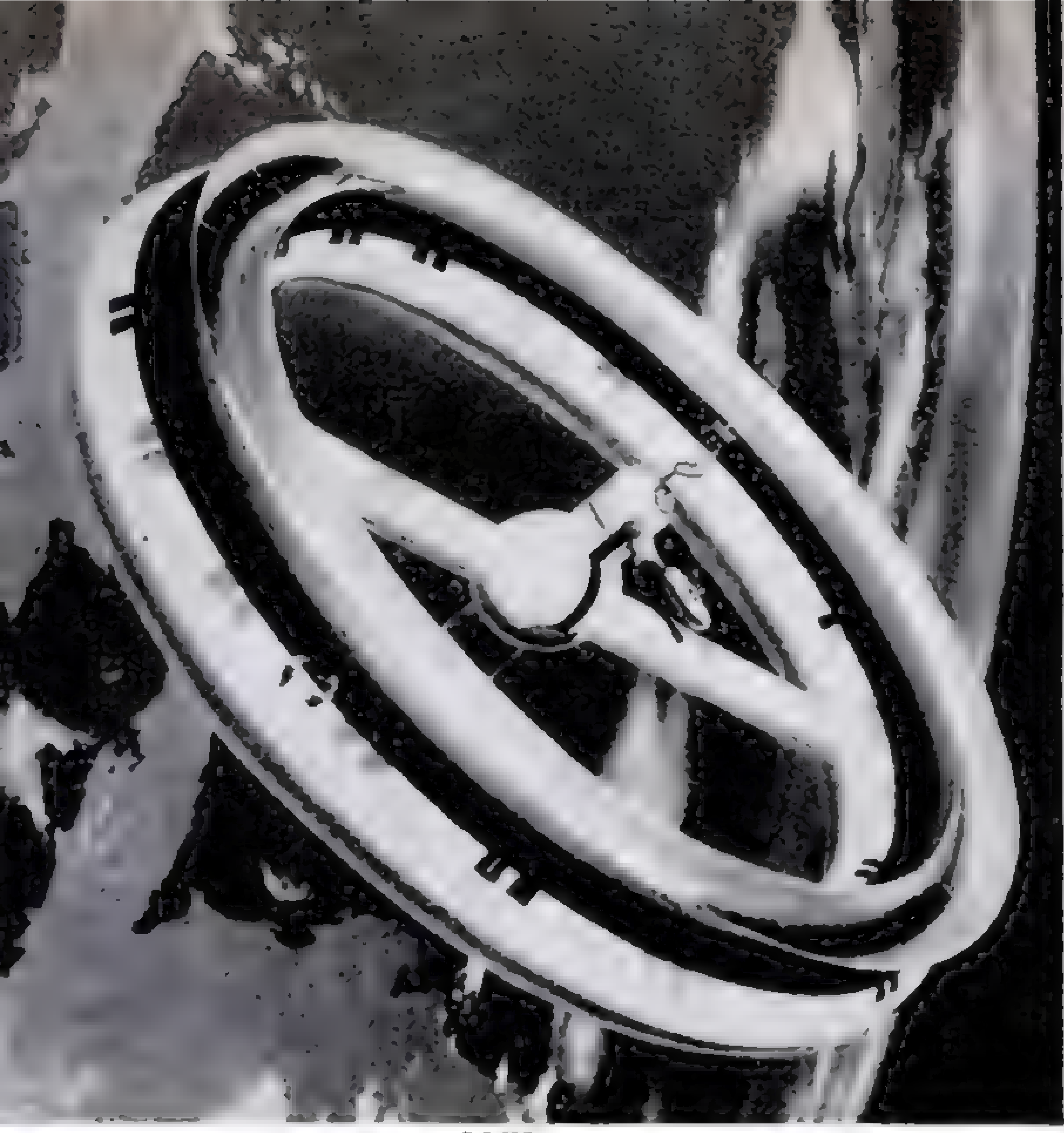
Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

DURING the years before Sputnik, several writers, including myself, predicted that one of the first objectives of manned space flight would be to establish one or more orbiting space stations.

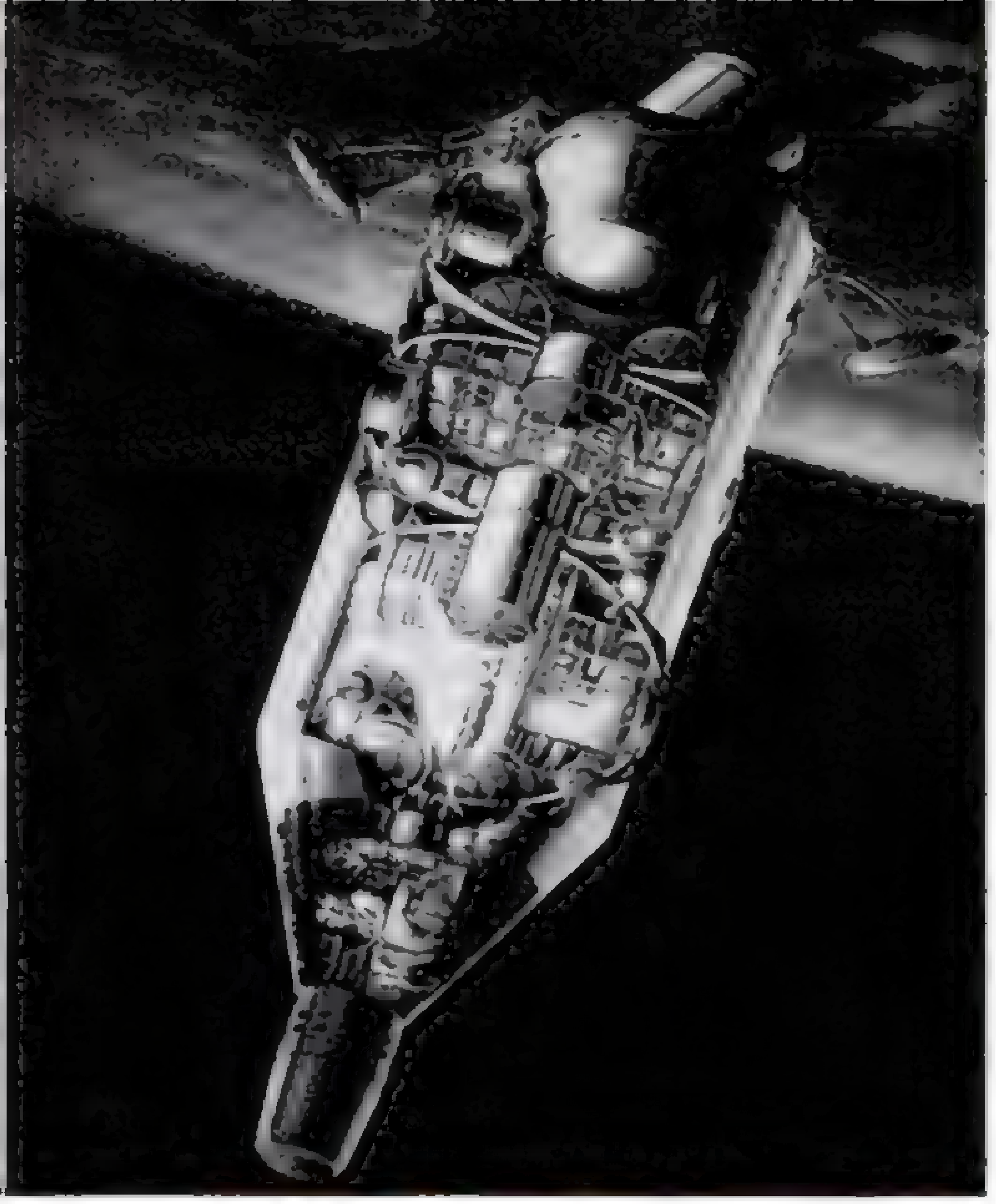
Today we're busy building rockets and spacecraft to take men to the moon. We have been fabulously successful with Project Mercury, and our Saturn I rockets have shown that they can reliably haul more than 10 tons of payload into orbit. Yet little is heard of manned space stations. Why is that so?

Actually the manned-space-station concept is just as exciting today as it was 15 years ago. There is absolutely no doubt that this country will have one or several such stations in orbit within a very few years. The reason a project for a space station hasn't been pushed more aggressively is simply that we don't know, yet, exactly how to build one best suited to the purposes it will serve.

Gemini to point way. As long as our manned-space-flight experience is limited to a total of about 53 hours logged by our astronauts, we cannot possibly specify the layout of a space station and all its many-faceted equipment in enough detail. Orbital flights by Gemini astronauts, in their two-man spacecraft, soon



Wheel-shaped space station was foreseen by Dr. von Braun as early as 1952, in Viking Press book "Across the Space Frontier" from which this painting by Chesley Bonestell is reproduced.



Manned Orbiting Laboratory with two-man crew, currently projected by Air Force, would help develop space-station plans. This design is proposed for it by Lockheed Aircraft Corp.

Space Stations?

will help close this gap in our experience. And, if the Air Force receives a long-awaited go-ahead, so will its Manned Orbiting Laboratory, designed to study man's ability to perform useful military tasks in space.

The Gemini astronauts, for the first time, will try orbital rendezvous and docking—a maneuver necessary to the operation of any space station. Inside and outside of their spacecraft, they will perform a whole slew of scientific observations and experiments. All this will give us a better idea of how much more can be accomplished by a manned space station than by an automatic observatory in space.

Using our space stations. Already we can foresee many tasks for which manned space stations can be immensely useful:

- Astronomical and astrophysical studies of sun, moon, planets, and the surrounding universe. Advantages of a space station would be freedom from atmospheric turbulence, and from the filtering effects of the earth's atmosphere on ultraviolet and other radiation.
- Observations of the earth's surface, for many purposes: weather forecasting, storm and flood warning, iceberg patrol, snowfall and water-resource management, prediction of volcanic eruptions and landslides, detection of forest fires, military reconnaissance, and navigational aid for ships and aircraft.
- Physical, medical, and life-sciences research. A space station is the ideal place for research on the effects of a number of conditions impossible to simulate on earth: prolonged weightlessness, space radiation of various types, a near-perfect vacuum of unlimited size.
- Maintenance of complex space in-

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What Happened to Manned Space Stations?

[*Continued from page 89*]

stallations. Consider a TV broadcasting satellite in a synchronous orbit—a station, seemingly standing still in the sky, to which anyone on earth below can tune his receiver. Several hundred kilowatts of transmitting power would be required. It may well prove to be economical to furnish a station so complex and powerful with a permanent maintenance crew, which would be exchanged at periodic intervals.

- A deep-space assembly site and jump-off platform for manned expeditions setting out to land on other planets. Such missions will require nuclear-powered spaceships, assembled and fueled in a low earth orbit from sections and propellants brought up by chemical earth-to-orbit freighters.

When we set out to design a space station, however, we face a strange paradox. To keep a man alive in outer space, we have to put a barrier between him and space—a pressurized cabin or suit—but it must not deprive him of the very gains he sought in space. If he cannot effectively observe the earth beneath him or the universe about him, he'll be like a man trying to study undersea life from a windowless submarine.

A related problem is raised by the question of possible ill effects from a long period of weightlessness.

Early space-station designs called for doughnut- or dumbbell-shaped stations rotating slowly about their hubs, so that centrifugal force would replace at least part of the missing gravity. But a spinning platform would handicap observers of the heavens and the earth, since telescopes require a steady aim.

Must space stations spin? We still do not know whether artificial gravity will be necessary from the medical point of view—and, if so, whether a daily five-minute spin in a small centrifuge built into a non-rotating space station might not suffice to make both the astronaut and the doctor happy. But the coming Gemini orbital flights, of up to two weeks' duration, will tell us a great deal about man's ability to endure weightlessness for longer periods.

In any case, artificial gravity undoubtedly would add to the comfort of everyday life in a space station. So a rotating design looks attractive for a manned TV station in space, and for the crew quarters of an assembly station for expeditions to other planets. For such long tours of duty, com-

CONTINUED

fortable living quarters for the crews will probably take precedence over suitability for scientific observations.

Space stations thus may differ in design according to their respective purposes. Likewise, their uses may dictate orbits of widely different types.

Unless the mission specifically calls for a high orbit, a low one offers the general advantage of lower earth-to-orbit transportation cost. A low west-east orbit, only slightly inclined to the equatorial plane, is particularly economical: It gives a rocket ship, at launching, full advantage of the "boost" resulting from the earth's west-east rotation. Such an orbit would best suit a space station intended as an astronomical observatory—or as a physical and life-science laboratory. A relatively low polar orbit, in contrast, seems advantageous for earth surveillance, since it would enable an observer to see every point on earth at least twice in 24 hours.

For an assembly site for deep-space expeditions, a low orbit in the equatorial plane offers certain advantages. And a TV station "fixed" in space automatically calls for an equatorial orbit, with the added requirement of a 24-hour orbital period (which, in turn, sets the required orbital height at about 23,000 miles).

The answer: many stations. To sum up, manned space stations are bound to come. Because of their varied potential uses, and different requirements, it seems likely that we shall have not one but a number of space stations—and that, in due time, other countries will have theirs, too.

It may well be, however, that several mission assignments for future manned space stations can be combined and served by one central station, when all participants can agree on an identical orbit. To reconcile the missions' different needs as to design, the orbiting space center may consist of a group of small free floating "mission" stations, clustered about a spinning doughnut or dumbbell that will serve as a combination hotel, restaurant, and office for the entire complex.

Dr. von Braun will consider answering questions from readers of Popular Science in the magazine, but he cannot undertake to answer each one by mail. Letters to him should be addressed in care of Popular Science, 355 Lexington Ave., New York, N.Y. 10017.

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When Will

An expedition on the way to Mars

"Mars Mission Module" envisioned in NASA drawing is manned earth-to-Mars spacecraft containing two other capsules: excursion module for descent to Mars' surface, and re-entry module for return to earth. Dish-shaped appendages shown extended at sides are solar collectors for generating power on the long interplanetary voyage.

A space authority takes a look at the rocket ship, equipment, and possible date for a manned interplanetary expedition

By Dr. Wernher von Braun

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

Dr. von Braun, seated, gives Rep. Roman C. Pucinski his views at House hearing on proposed National Science Information Center.

NOW that we have an unmanned spacecraft on the way to Mars, and have already sent a highly successful one past Venus, the question is being heard, "When may we expect manned interplanetary expeditions?" For a realistic answer, let us appraise the magnitude of the task and compare it with our present capabilities.

Suppose we try to describe, as best we can today, what the first manned expedition to Mars may really look like:

Place of departure. It is fairly certain that a manned Mars expedition will not start from the earth's surface—but from a low "departure orbit" around the earth. There, the interplanetary ship will be assembled, from loads hauled up by earth-to-orbit cargo rockets.

Size of crew. A Mars expedition may require a crew of 6 to 10, or more. For an interplanetary voyage, there are several arguments for a bigger crew than the trio of astronauts who will make the much briefer Apollo moon trip. The length of the Mars expedition increases the chances that a crew member might become sick and require a doctor's care, as well as replacement. Adding a few crew members can give

We Land on Mars?

The homecoming—full-speed re-entry

Crewmen lie on couches, arranged in two tiers, to take G forces of hitting earth's atmosphere at high speed, in NASA conception of Mars expedition's re-entry capsule. Dispensing with rocket braking saves having to haul propellants for it all the way to Mars and back.

the expedition much greater scientific usefulness. And since the equipment will be more complex than for a moon trip, it will need more monitoring and maintenance.

The interplanetary rocket ship. For its power maneuvers, in earth orbit and near Mars, we can assume that the spaceship will be designed to use one of these two forms of propulsion:

- High-energy chemical engines, burning liquid hydrogen and liquid oxygen.
- Nuclear engines, of Rover type with a solid core, using liquid hydrogen as the sole propellant. These would provide nearly twice the "specific impulse" (a measure of propulsive efficiency) of chemical engines.

Payload. Besides the weight of the ship itself, its crew, and its propellants, we shall have to plan for sizable items of payload, including:

- Enough oxygen, food, and water to supply all the crew members for the duration of the expedition.
- A simple radiation shelter—since bursts of solar radiation, reasonably predictable for short periods like that of an Apollo round trip to the moon, cannot be forecast for the long time span of a voyage to a planet and back.
- A spinning crew compartment to provide artificial gravity, or at least a centrifuge for occasional exposure to it.
- Radio equipment capable of covering interplanetary distances reliably.

To arrive at any estimate of what all these items will total, we must now examine such things as the distance, time, and flight plan in more detail.

Distance. Comparison with a flight to the moon will help to put an interplanetary flight in perspective. The average distance between earth and moon is 238,860 miles, and a typical Apollo trajectory is only slightly longer.

Venus' and Mars' closest approaches to earth are 26 million and 35 million miles, respectively. But Mariner II had to travel along a curved circum-solar trajectory of 180 million miles to intercept Venus. Mariner IV, now headed for Mars, will have covered 325 million miles before getting there.

Flight times. A typical one-way flight to the moon requires 2½ to three days. Mariner II's flight to Venus took almost four months. Mariner IV will be on its way to Mars for eight months. These are one-way flight times. However,

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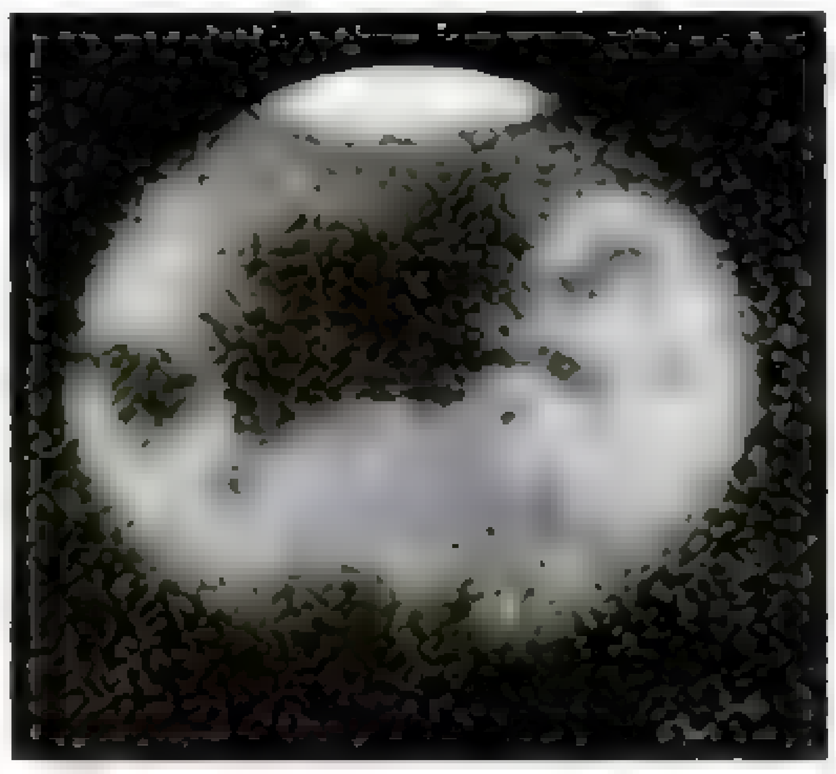
nobody wants to go on a one-way trip into space.

A typical Apollo round trip to the moon, including a 24-hour surface stay, will last about 10 days. A typical estimate of round-trip flight time for a manned expedition to Mars is 400 to 450 days, including a 20-day stay on Mars. This takes into account the fact that, to get back from another planet with a reasonable expenditure of propellants, the return flight must be made when that planet and the earth are in reasonably favorable positions in their orbits.

Velocity requirements. To reach the moon, a spacecraft must acquire a speed just a trifle less than the earth's escape velocity, which is the speed required to escape permanently from the earth's gravitational pull.

For a one-way flight to Venus or Mars, the spacecraft need not reach a very much higher speed. Just a trifle *more* than escape velocity suffices to carry it out of the earth's field. The spacecraft will enter a circum-solar orbit that will carry it farther away from the sun (for instance, to Mars) or closer to the sun (for instance, to Venus), depending on whether the excess speed is in the direction of the earth's orbital motion around the sun, or in the opposite direction. The actual velocity at which the spacecraft enters its trajectory to Mars or Venus will equal the earth's own tremendous orbital speed, 18½ miles a second, plus or minus that small excess speed with respect to the earth.



Planet Mars challenges spacemen to land and solve its mysteries. Telescopic photo shows its mottled surface and white polar cap.

For the return trip, the velocity requirements are of the same order of magnitude as for the outbound voyage. But every ounce of rocket propellant to be consumed in leaving Mars represents payload for the outbound leg of a Mars expedition's journey—and many more ounces of propellant must be consumed to get it there. This is a fundamental difference between the power requirements for a one-way and a round-trip interplanetary mission.

Landing on a planet. For man to set foot on a planet, he must first retard his spacecraft so the planet can "capture" it. From the resulting orbit around the planet, the explorers can then descend to its surface in a landing capsule that, of course, must provide rocket propulsion for re-ascent to orbit when the surface mission is completed.

In principle this resembles the lunar landing and re-ascent with the Apollo "Bug." In landing on a planet with an atmosphere, however, judicious use of aerodynamic braking can conserve the expedition's supply of rocket propellants.

Re-entry. Using aerodynamic braking to save rocket propellants becomes particularly important during the terminal maneuver of a Mars expedition—the return into the earth's atmosphere.

Reaching another planet takes more than earth-escape velocity, we have noted; and a returning spacecraft will likewise approach the earth's atmosphere with a speed in excess of earth-escape velocity. Thus return from Mars or Venus will always be at higher velocity than the sub-escape speed at which an Apollo Command Module returns from the moon.

If we can build a Command Module for a Mars expedition that can safely withstand the higher re-entry speed, we can avoid having to slow it down with rocket power to sub-escape speed as it approaches re-entry. This would be of great practical significance—for any power braking would have to be done with propellants hauled all the way to Mars and back, just for this final maneuver. Fortunately it looks as if such super-escape-speed re-entry capsules can indeed be built.

How it adds up. From all the foregoing facts, we can now estimate the

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When Will We Land on Mars?
[Continued from page 88]

weight of the spaceship for a Mars expedition, fully loaded and ready to go.

For a specific example, let us take a Mars expedition with a crew of eight men, a favorable opportunity such as 1986, a stay on Mars of about 20 days, and "full-speed" aerodynamic re-entry into the earth's atmosphere. We then find:

The departure weight of the all-chemical interplanetary ship will be about 4,000,000 pounds. The figure for the all-nuclear ship will be about 1,600,000 pounds. That is what must be carried up by cargo rockets and assembled in earth orbit.

Let us assume these cargo rockets are outgrowths of Saturn Vs, the most powerful type under development today. Saturn V's earth-to-low-orbit payload capability is about 250,000 pounds—which in due time can probably be stretched to enough more than 330,000 pounds so that three of these advanced Saturn Vs would lug a million pounds of cargo into orbit.

Thus, 12 of the advanced Saturn Vs could haul the weight of the chemical Mars ship into earth orbit—and five of them, the nuclear Mars ship. However, the number of supply flights actually needed may be twice as high, due to the extended duration of the orbital assembly operation—which leads to propellant-evaporation losses and requires assembly-crew rotation.

The figures are high, though not prohibitive. In space, as elsewhere, we must learn to crawl before we can walk—and obviously we have a lot to learn before we can begin to think of mounting a manned interplanetary expedition.

How far along are we?

Launch vehicles and spacecraft for a manned landing on the moon are rapidly approaching reality. Rocket engines and guidance equipment are in an advanced state of ground testing. First parts for flyable stages and spacecraft modules are reaching the assembly floor.

Less than two years from now, a Saturn IB rocket will loft the first manned Apollo spacecraft into earth orbit. Before the end of this decade, if all continues to go well, a huge Saturn V rocket will hurl three astronauts in a similar spacecraft into a trajectory to the moon.

And the launch date for the first manned Mars expedition? Maybe 1986 wouldn't be a bad year, from all angles. ■ ■

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Here is the suit that will protect those who walk upon the first celestial body to be explored by earthmen

What an Astronaut Will Wear on the Moon

By Dr. Wernher von Braun

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

SPACE suits in which Apollo astronauts will walk the surface of the moon have come a long way from the pressurized diving rig of rubberized canvas, topped by a cylindrical metal helmet, in which Wiley Post in 1934 attempted to break the world's altitude record.

The list of the Apollo suit's requirements is so long, and they are so conflicting, that for a long time some of the people closest to the problem ex-

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Moon suit's needs make "shopping list for Santa Claus"

Formidable number of requirements, many of them conflicting, has had to be met by designers of Apollo garb. Dr. von Braun (center) and others at Marshall center inspect a Navy flight suit, the design of which is similar to that of Apollo space suit pictured on the preceding page.

pressed serious doubts whether the job could be done at all.

What a moon suit must do. Just for a sample of the needs, this suit must:

- Protect the wearer from the vacuum of space when the command module, or crew cabin, is depressurized—and when he is outside of it.
- Keep the temperature around him comfortable, in all the following situations: inside the air-conditioned command module; outside the command module, both in bright sunlight and in the earth's shadow, during unpowered flight through space; and on the lunar surface, during day and night.
- Provide a compatible backpack whose oxygen supply will last several hours—and can be renewed, by plugging in to the ship's oxygen supply, for periods up to several weeks.
- Enable the wearer to eat and drink, under zero-gravity conditions, without breaking the suit's sealed atmosphere.
- Permit him to communicate by voice when the command module is pressurized and the three astronauts have their faceplates open; and by radio, outside the ship and on the moon's surface.
- Give him a reasonable degree of protection from micrometeorites when he is walking on the lunar surface.
- Permit storage and collection of body wastes, and have provisions for eliminating them.
- Enable the wearer to walk comfortably over rugged terrain on the moon (where the gravity is only one-sixth of what it is on earth), with the suit pressurized and backpack in place.
- Allow him to get back on his feet unaided, if he should stumble and land on his back like a June bug.
- Permit him to do work requiring some manual dexterity, with his suit and gloves pressurized.
- Be light and flexible—yet sturdy enough to avert critically dangerous punctures by contact with jagged rock formations on the moon.
- Enable the Apollo astronaut to shed or don it quickly in the cramped space of his command module, under zero-gravity conditions and without help.

These dozen items' desirability will be as obvious as the difficulty of providing them. They have been likened to "a shopping list for Santa Claus."

The Apollo moon suit is the answer to this imposing array of specifications. It is being developed by the Hamilton Standard Division of United Aircraft, at Windsor Locks, Conn., under a contract with NASA's Manned Spacecraft Center, Houston, Tex.

How Apollo suit fills the bill. The forthcoming moon suit is best described by progressing, stepwise, from the astronaut's skin outward.

To remove body heat effectively, the innermost garment is a set of water-cooled long johns, worn directly on the bare skin.

[Continued on page 210]

What an Astronaut Will Wear on the Moon
[Continued from page 88]

Pictures of Mercury astronauts emerging sweat-drenched from their capsules have conveyed, in a rather telling way, the need of active cooling for a man hermetically sealed in a pressure suit. Oxygen circulated through the Mercury suit, before launch and during flight, was called upon to remove body heat. But water-circulating plastic tubes, embedded in a net-weave undergarment, have been found far more effective—and are therefore used in the Apollo suit.

The heat absorbed by the cooling tubes is dissipated in the astronaut's backpack by a porous-plate "sublimator"—a novel sort of radiator for space conditions. Warmed water from the cooling tubes is sucked into pores of a plate whose other side is exposed to the ambient vacuum. The water freezes in the pores, due to pressure drop and evaporation.

As the resulting ice sublimes (evaporates without melting) into the vacuum outside, the "ice plug" in each pore grows thinner. Ultimately it blows out, the pore refills with water, and the cycle is repeated. Thus the porous plate serves as a stationary heat-rejection device.

A thin layer of nylon, whose texture and function can best be compared with those of a shirt, surrounds the water-cooled undergarment. This nylon layer also supports oxygen ducts, and wiring for medical instrumentation taped to the astronaut's body.

Next comes the sturdy "pressurization layer," a heavy bladder of neoprene-coated nylon. Its main function is to seal within the suit the astronaut's pure-oxygen atmosphere, which is at an absolute pressure of five pounds per square inch—about one-third of the atmospheric pressure on earth.

As could be expected, the design of easily movable joints at hips, knees, shoulders, and elbows posed a most formidable problem. For any flexible L-shaped joint, unless especially configured, has a natural tendency to straighten out under internal pressure. Of course this would mean that an astronaut thus encased would have to use brute force (and plenty of it) to bend a knee or an elbow.

Making joints easy to bend. The answer to this dilemma is the "convoluted joint"—a rubberized bellows joint, so designed that its total internal volume does not change as it is deflected. A complex system of internal nylon and wire prevents the bellows from

CONTINUED

expanding like an overpressurized accordion.

Other vital elements tied to the pressurization layer are the pressure-glove and boot connectors, and the helmet ring. Pressure gloves and boots are attached to the suit with quick-connect O rings and bearing seals to prevent oxygen leakage. The fiberglass helmet of the Apollo suit can be rotated on the astronaut's shoulders, if he so chooses, as he turns his head.

An outer restraint layer of nylon, aluminized on the outside, encloses the pressurization layer. It is this aluminized nylon layer that you see in the photograph of the Apollo suit on the opening page.

A "thermal overcoat," too. On the lunar surface, the Apollo astronaut will don in addition a loosely fitting overgarment—a two-piece set of pants and cloak of aluminized mylar and nylon. This will provide him with additional protection from the extremes of temperature between sunlit and shaded areas on the moon. It will also serve as a protective shield against grain-of-salt-sized micrometeorites, which are believed enough of a hazard on the lunar surface to warrant this extra protection. This thermal overcoat is contoured to fit over the life-support and communications backpack.

That is a preview of the way the Apollo astronauts will be dressed for the great adventure of setting foot upon the first of the celestial bodies to be explored by earthmen. ■ ■

About the "Crunchy Noise" of Lunar Footsteps

In an earlier article, Dr. von Braun ventured the opinion that an astronaut walking on the lunar surface, which may resemble hard snow in texture, "may hear a crunchy noise." But didn't he know, a number of PS readers took pen in hand to ask, that the moon has no atmosphere to carry sounds?

Of course he did; and his explanation is simply this: Suppose you were sitting in a car with tightly closed windows, and someone crushed a hard snowball against the outside of the car. The crunching sound would be transmitted right through the metal of the car's body, to the air inside the car, and so to your ears.

Likewise, the sound of an astronaut's lunar footsteps could be expected to be transmitted through his footgear to the oxygen atmosphere inside his suit—and so he would hear it.

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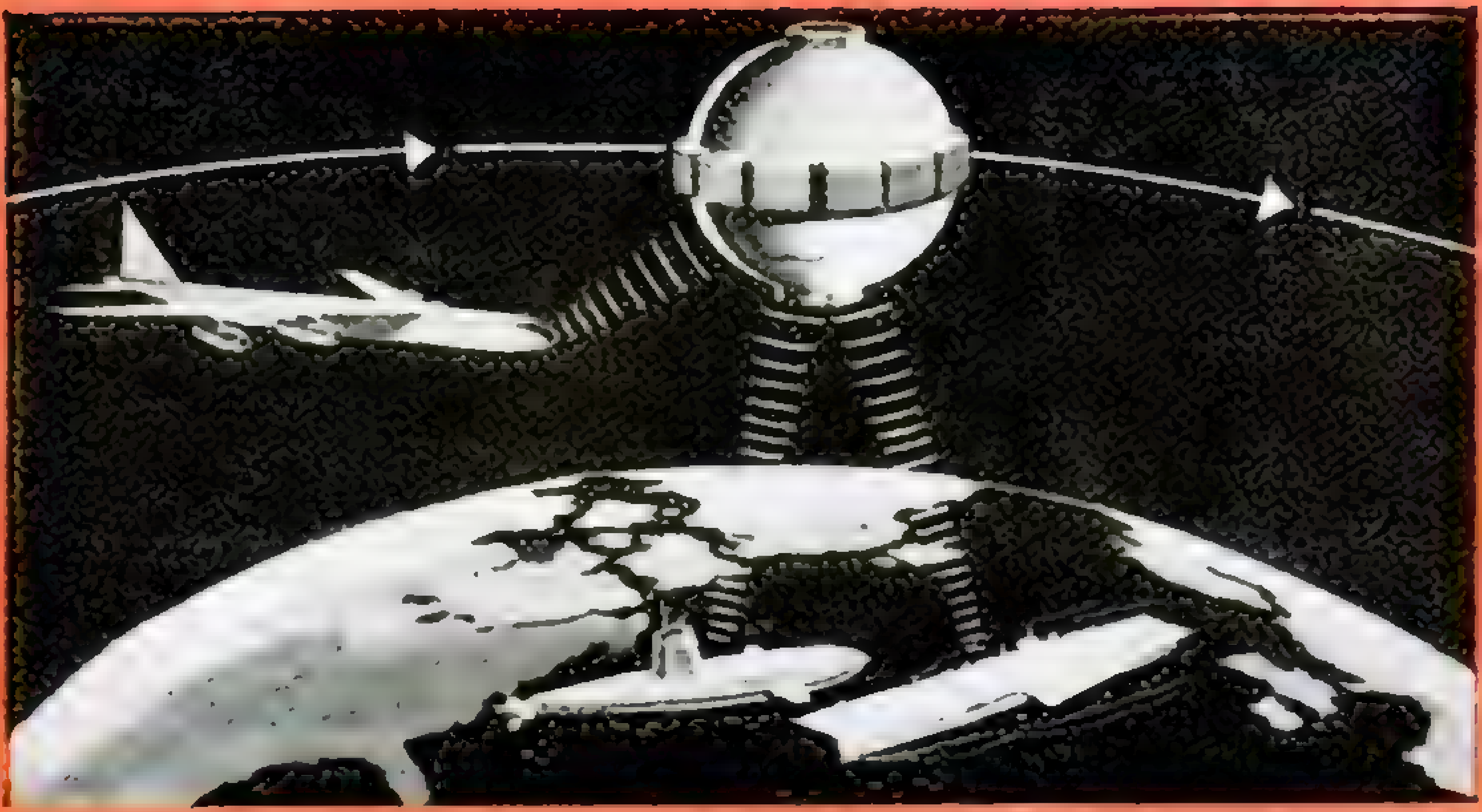


Satellites can provide all-weather, day-and-night navigation system for surface ships, Polaris submarines, and planes, as visualized in NASA drawing of concept. It frees craft from dependence on "shooting" sun and stars as in classical navigation—or on ground-based radio aids, which may not be adequate, or cooperative, where needed.

More accurate than celestial navigation, a new way for craft to get their bearings has been placed in service by the U. S. Navy

Ships and Planes

By Dr. Wernher von Braun

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

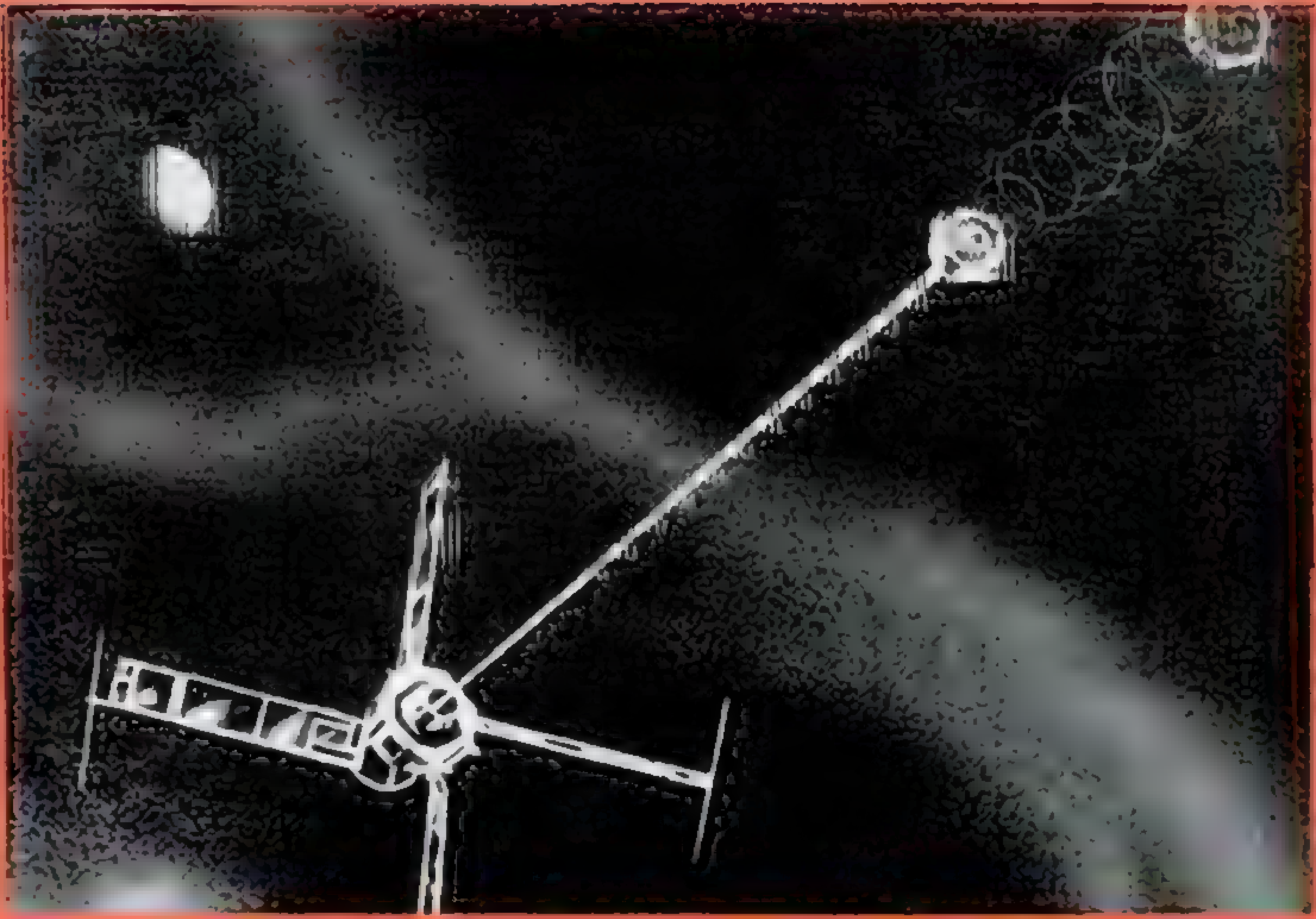
SINCE last July the U. S. Navy has conducted extensive tests of a navigation system for ships that uses three satellites especially designed for the purpose. These Transit satellites were placed in near-circular orbits 600 miles high, by the time-tested Thor-Able Star rocket, from Vandenberg Air Force Base on the west coast. The tests seem to have been highly successful, for the Navy recently declared the whole system ready for operational use.

How can satellites be used to navigate ships? The basic idea is simple:

A small satellite equipped with receiver, transmitter, and a signal-storage device is launched into orbit. Its orbital data, determined by ground tracking stations, are transmitted back to the satellite in suitably coded form—and stored, much as with a tape recorder, by a magnetic memory. Should the satellite gradually change its orbital path, the older information may be replaced by updated tracking data. Thus the satellite, whenever interrogated from the ground about its orbital path, is ready to give up-to-date information. This is the first half of the story.

The other half concerns determining the *relative* position between the satellite and a ship that seeks to learn its own *absolute* position on the globe.

The Doppler shift. This relative position is found by measuring the pattern of the so-called Doppler shift of the satellite's transmitter frequency. Radio Doppler shift is the electronic counterpart of the familiar acoustic phenomenon that the pitch of a locomotive whistle drops as the train passes you. While the train is approaching, the sound waves hit your ear at a frequency higher than that emanating from the whistle. As the train re-



Official Navy drawing shows one of its three navigation satellites currently circling earth in system recently announced to be operational. This one uses solar cells for power. Weight at end of mast gives satellite a dumbbell shape that aligns it with pull of gravity. Spring, linking weight to mast, damps and curbs swaying.

Navigated by Satellites

cedes, you hear a frequency lower than that of the whistle's original tone.

In the case of Transit, the pattern of the Doppler shift from high to low clearly shows the nature of the satellite's pass with respect to the ship. If the change from high to low is rather abrupt, the satellite is at a high elevation. If the change is more gradual, the satellite is lower above the horizon. In addition, the Doppler shift is greater in a head-on overhead pass than in a slanting pass.

A land surveyor finds his absolute position by measuring his relative position against several landmarks whose absolute position he knows. The navigational satellite is only one landmark whose absolute position we know. But, since it is moving with astronomical precision through a predictable, accurately surveyed orbit, it actually offers many precisely surveyed landmarks at different times during one overflight.

With the Doppler-shift data simultaneously providing the relative positions between ship and satellite, the absolute position of the ship can be determined exactly. The Navy says that a navigational fix taken with the Transit satellite system is accurate within about one-tenth of a mile. (Celestial navigation is consistently accurate only to within one-half mile.)

Shipboard equipment used in the Navy's operational Transit tests works automatically. It activates itself when the satellite approaches; receives both the Doppler shift, and the satellite's latest

[*Continued on page 193*]

Dr. von Braun tries periscope of one of Polaris subs, the Von Steuben, aided by satellites.

Ships and Planes Navigated by Satellites

[*Continued from page 77*]

orbital data; computes the "fix"; and even types the results, in latitude and longitude, for the navigator.

On a production basis, the Navy estimates, the shipboard equipment could be built for about $12,000 a set. Thus, use of Transit satellites for navigation would be entirely within reach for commercial shipping. Since the system, as a Navy spokesman puts it, offers an "accurate, dependable, worldwide, all-weather, 24-hour-a-day passive navigational-fix capability," Transit should find a lot of takers.

For subs and aircraft, too. One of the hottest customers, of course, is the Polaris submarine fleet. For the effectiveness of these missile-launching subs depends on accurate all-weather position information, gained without betraying the ship's location by sending radio signals.

The Transit system seems equally suited for use by aircraft. Potential advantages are obvious for military or commercial planes, flying over oceans or large land masses without adequate (or cooperating) ground-based radio-navigation aids.

The navigation satellites weigh about 150 pounds, and thus require only modest boost power. For global capability they must be placed in polar or near-polar orbits, so that the spinning earth will expose its entire surface to the satellite. A series of suitably spaced satellites provides around-the-clock coverage.

Transit satellites have special features worthy of mention: They are "gravity-gradient stabilized," which means they apply the phenomenon that a dumbbell-shaped object placed in earth orbit tends to align itself in the direction of the earth's gravitational pull. Transit's transmitters are equipped with oscillators that stabilize the transmitted frequencies with an accuracy of one part in ten billion, for utmost precision in determining the Doppler shift.

The electronic equipment of two of the three Transit satellites is powered by an array of 18,000 solar cells. The third one uses a SNAP-9A nuclear-power source—an atomic battery in which heat from plutonium 238 is converted by thermocouples into about 20 watts of electricity. Both solar and nuclear power sources provide lifetimes far in excess of the Transit satellites' guaranteed two-year usefulness.

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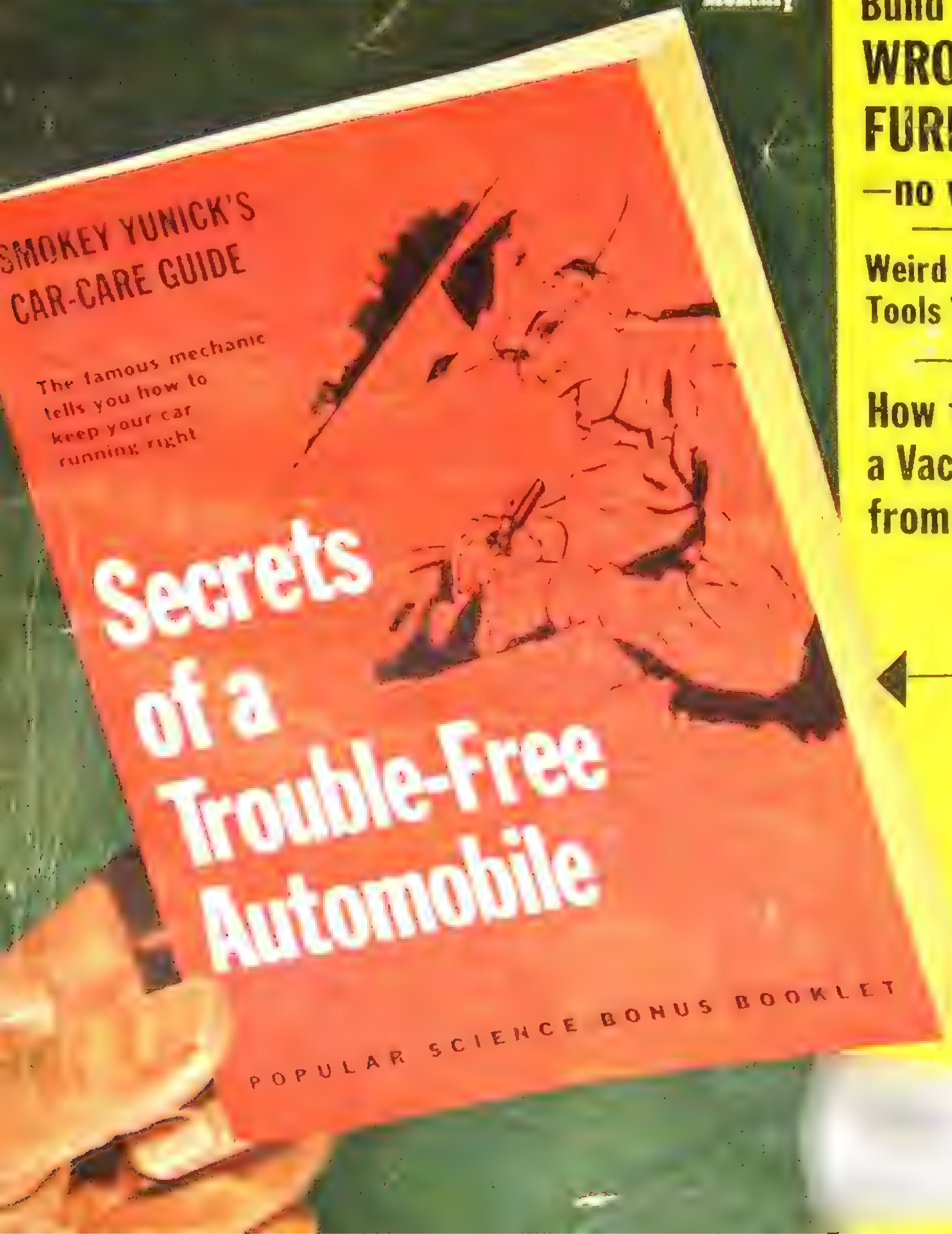

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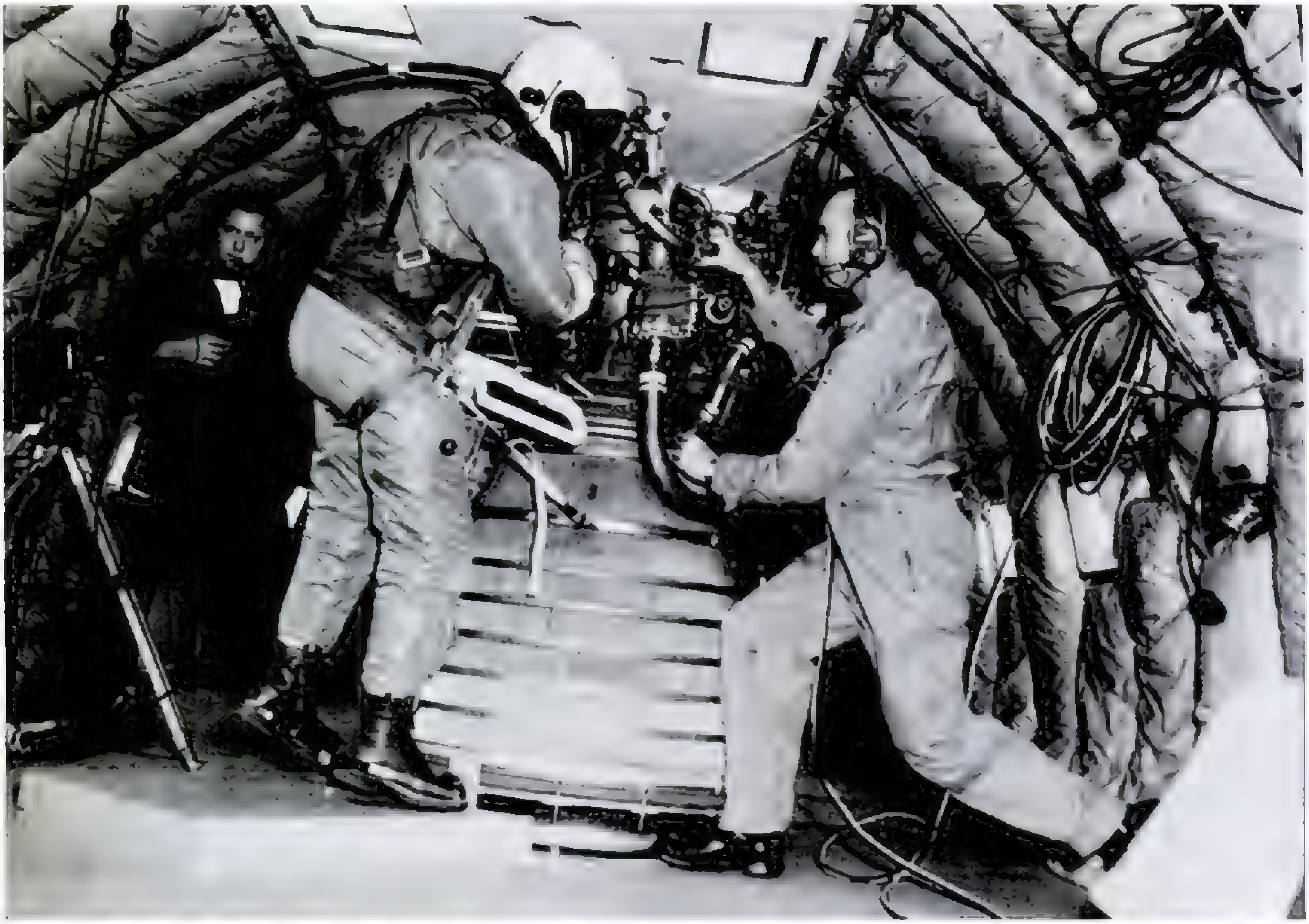
How space voyagers will live in—

The Strange World of



In plane flying zero-gravity course, spacemen repair rocket engine with special space tools.

Keeping a meal from floating away, avoiding jet-propelled sleepwalking, going outdoors as a human satellite—these are problems now being solved

By Dr. Wernher von Braun

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

WHEN an astronaut becomes a human satellite, floating freely in the vastness of space, he offers a dramatic example of the weird things that can happen in the realm of zero gravity—a strange world just beginning to be explored.

In the Soviet space flight of last March 19, Lt. Col. Alexei Leonov left his orbiting Voskhov 2 spacecraft and sailed along beside it for 10 minutes, at nearly 18,000 m.p.h., before returning along his trailing lifeline.

His eerie experience will be shared,

Zero Gravity

Dr. von Braun, pointing to viewing screen in Cape Kennedy blockhouse, watches successful launch of Pegasus satellite by Saturn rocket.

within only a few months, by our own spacemen. In one of the next Gemini flights an astronaut is to emerge from his orbiting capsule—and possibly perform a simulated repair on its exterior with a special space tool. Before that, a Gemini astronaut will have made the preliminary trial of opening the spacecraft's hatch and venturing halfway out.

What is zero gravity? Subject to this strange environment is any spacecraft coasting unpowered through space—around the earth, or on the way to the moon or a planet. Inside the craft as well as out, space voyagers find the familiar law of gravity apparently repealed. Any loose objects, astronauts included, will float about instead of staying put in seats or receptacles.

Actually, zero gravity or weightlessness does not mean at all that gravity has ceased to operate. It results, rather, from a situation where both the spacecraft and its contents can freely follow the identical forces of gravity. Once a spacecraft has been "injected" into any kind of unpowered trajectory in a vacuum, its hull, its crew, and its contents will faithfully obey the laws of motion governing all heavenly bodies—and so, there can be no relative forces between them. Living and housekeeping under zero gravity, therefore, pose curious problems:

Jet-propelled sleepwalkers. Before going to sleep, astronauts will need to strap themselves down, or they would float about the cabin, propelled by the thrust of their own breath.

Sponge baths, rather than showers, must be the style for bathing under zero gravity.

Like babies, astronauts will drink from squeezable plastic bottles. If a spaceman tried to get water out of an ordinary bottle, it would be like the problem you encounter when you try to pour catsup on your hamburger—first you get none, then more than you want.

For short trips, food for astronauts will be taken along in dehydrated form. Water will be injected into the plastic food bag and, after a bit of kneading, the astronaut will squeeze the resulting creamy substance into his mouth by pulling the bag through his closed teeth.

It is interesting to note that astronauts have no difficulty in swallowing under zero-gravity conditions. The esophagus is equipped with a series of ring muscles that force the food down to the stomach, regardless of the presence or absence of gravity. This action is so effective that it even works *against* gravity: You can eat while standing on your head!

Longer trips will call for more comfortable ways of eating. As a minimum, astronauts will want warm food of the "add water, heat, and serve" type.

For planetary voyages lasting several hundred days, you can rest assured that it will be shrimp cocktail, filet mignon, Waldorf salad—the works. Spacecraft pantries will have more or less conventional deep-freeze compartments, infra-

[*Continued on page 198*]

The Strange World of Zero Gravity

[*Continued from page 69*]

red broilers, coffee dispensers, and spice cabinets. Even the most luxurious space cuisine for long-duration voyages, however, will avoid needless food wastes: All meat will be boneless and free of undesirable fat; potatoes will be peeled in advance; cherries will be stoneless. If a Martini is ever served aboard a spacecraft, it may come without an olive.

Foiling a steak's escape. Ingenuity will be required of designers of tableware for gracious dining under zero gravity. Dishes will need spring-loaded covers so a steak won't float away. (And, of course, the dishes themselves must somehow be anchored.) Forks are fine, but spoons are useless. Knives either will use saw action to minimize cutting pressure, or will be replaced by scissor-type devices that can do without any one-sided pressure.

Tools for use under zero gravity will have special designs, too. If a weightless astronaut tried to tighten a nut with an ordinary wrench, the effort would only spin him around. Instead, he'll use a "squeeze wrench" that does not require a firm foothold to apply a twist.

Cleanliness is the key to good housekeeping, in space as at home. And, under zero gravity, rigorous cleanliness is even more important than at home. Once up in orbit and under zero-gravity conditions, any dust or dirt in a spacecraft would not harmlessly settle under a chair or on a rug. It would float around—and could be inhaled, or short-circuit electrical terminals, or be sucked into the air-conditioning system. That's one good reason why zwieback wouldn't be popular in a spacecraft.

Tidiness starts early. The spacecraft is assembled and checked out under "white-room conditions" comparable to the cleanliness standards of a hospital operating room. Even when perched on top of the huge launch rocket prior to takeoff, it is surrounded by a servicing room operated under white-room standards. After the astronauts leave their specially equipped Transfer Van, they ride up a spic-and-span elevator to that servicing room, located on the top floor of the gantry. Before entering the spacecraft they remove special shoe covers. All these precautions are to prevent any dirt or dust from getting into the craft at any time before takeoff.

 CONTINUED

Any loose tools or pieces of special equipment used within the spacecraft must have their proper storage spaces or tie-up straps. A monkey wrench, harmlessly floating in a corner of a spacecraft for weeks of zero gravity, can turn into a deadly missile the moment the rocket engines are turned on, or the decelerated reentry into the atmosphere begins.

So far we have discussed zero-gravity problems that can be foreseen quite clearly. We cannot yet speak with equal assurance about the most important one of all:

Man, the question mark. A great deal has been written and speculated about man's ability to live and perform under zero gravity over extended periods of time. To date, we know this much:

Our Mercury and Gemini astronauts have experienced many hours of weightlessness in their orbital flights. Leroy Gordon Cooper, who circled the earth for more than 34 hours on May 15 and 16, 1963, performed a brilliant manual reentry maneuver at the end of his 22-orbit flight—demonstrating convincingly that his effectiveness and precision had not suffered one bit. Soviet astronauts have returned from orbital flights lasting up to 95 hours, apparently likewise without detrimental effects. There is no substance whatever to the widespread rumors that one or more of our astronauts are still suffering from ill after-effects of weightlessness experienced during their flights.

Nevertheless it would be rash to say that extended zero gravity could pose no serious physiological problems. In flights aimed at a landing on the lunar surface, firmly scheduled for this decade, our Apollo astronauts will be under zero gravity, on and off, for periods of up to 10 days. Only in some of our forthcoming Gemini flights do we expect to learn what such longer periods of weightlessness will do to the crew and its ability to perform with dispatch and precision.

Meanwhile we can assume that, to retain their physical fitness during extended space flights, astronauts will need equipment for regular physical exercise—and this will be easy to provide. Sporting-goods stores are full of exercisers, ranging from simple stretch belts to elaborate rowing and pedaling machines, that will lend themselves well to use under zero gravity in outer space. ■■

JULY 1965 35 CENTS

Popular Science

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What's Coming in '66 CARS

How to Cure VAPOR LOCK
See: All About Carburetors

Four Brutal Years on a FLOATING ICE ISLAND

ART ARFONS: HOW I'LL DRIVE FASTER THAN SOUND

Amazing No-Fuel "Space" Engine You Can Build

PAGE 106

Do Your Own HOME WIRING

Gemini orbit-changing opens door to—

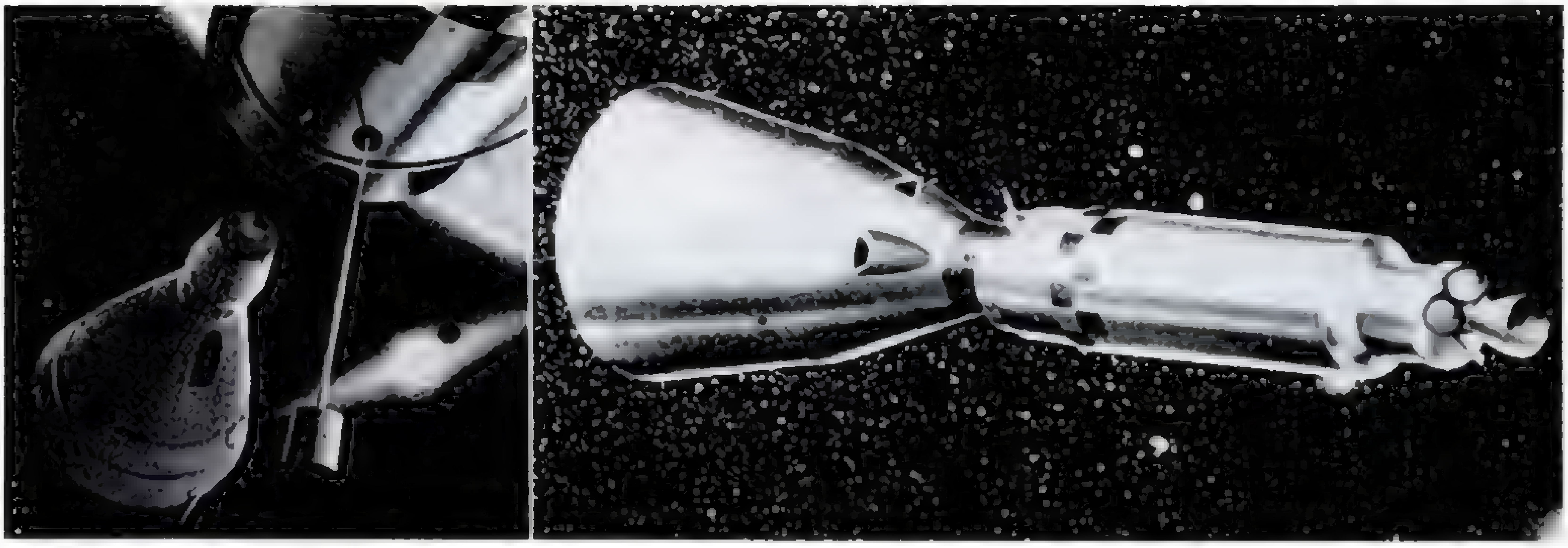
A Rendezvous

Guiding craft to a meeting, soon to be tried, will be key maneuver in going to moon and to space stations

Dr. von Braun takes pilot's position (far side) in Gemini simulator used for trials at NASA's Manned Spacecraft Center, Houston, Tex.

in Space

By Dr. Wernher von Braun
Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.



Gemini spacecraft will maneuver to approach Agena target vehicle, then latch on to it.

WHEN a Gemini spacecraft's pilot altered its orbit, in the space flight last March of Maj. Virgil I. Grissom and Lt. Cmdr. John W. Young, the feat was hailed as historic. For the first time, a manned spacecraft was maneuvered from one orbit to another. In this case, there were three successive changes, both in the height and in the inclination of the orbit.

The feat was important because it was the first successful trial of a system designed to maneuver a manned spacecraft for rendezvous and docking. And the capability of two space vehicles to meet, and latch on to each other, is a key requirement for many coming space-flight objectives.

For example, Apollo's Lunar Excursion Module, bearing two astronauts returning from the lunar surface, must rendezvous and then dock with the Service and Command Module. The latter, with its lonely "shipkeeper," will have been orbiting around the moon during the LEM's descent to the lunar surface and its re-ascent. Rendezvous is the only way to get all three Apollo astronauts back to earth.

Space stations, repair missions, space refueling, and satellite inspection will all require a well-developed technique of orbital rendezvous and docking.

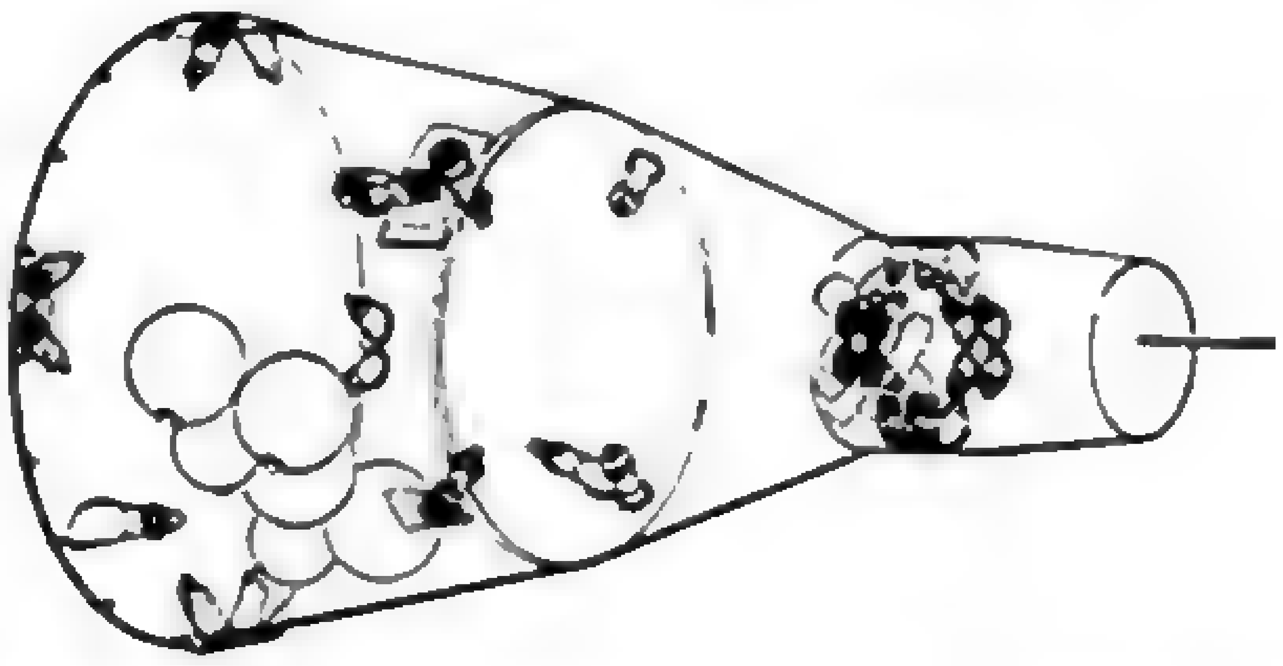
Rendezvous. Our two-man Gemini spacecraft, designed specifically with rendezvous and docking in mind, will soon attempt just that. Flight GTA-6—the fourth manned Gemini flight, scheduled for this fall with Cmdr. Walter M. Schirra as pilot and Maj. Thomas P. Stafford as co-pilot—now has definitely been assigned to carry out the first actual rendezvous and docking mission.

Out of a number of possible rendezvous flight profiles, the so-called concentric-orbit method has been chosen.

An unmanned Atlas/Agena D target vehicle and the two-man Titan II/Gemini spacecraft will have a simultaneous countdown at Cape Kennedy.

The target vehicle will be launched

[*Continued on page 162*]



To change orbits, Gemini uses 16 small thrusters (black dots show nozzles) on wide part of craft. Others on narrow nose aid in reentry.

A Rendezvous in Space
[Continued from page 59]

first. After Atlas burnout, the Agena D will be fired up and injected into a circular orbit 160 miles high, inclined 28.87 degrees to the plane of the equator.

About 100 minutes later, on the first orbital pass of the Agena over the Cape area, the two-stage Titan II launch vehicle must inject the Gemini spacecraft into an elliptical orbit inside the Agena's circular one. This elliptical orbit is to have a perigee, or lowest altitude, of 87 miles; and an apogee, or highest altitude, of 140 miles. (All distances, thus far and subsequently, are in nautical miles; the corresponding figures in ordinary statute miles would be about 15 percent larger.)

It is very important that the Agena's and Gemini's orbits be nearly "co-planar" —in the same plane, like two figures drawn on the same sheet of paper. The permissible inclination between the two orbital planes is approximately half a degree.

To attain such accuracy is quite a trick. During the 100 minutes that elapse between the launches of target vehicle and spacecraft, the earth's spinning will turn the Cape Kennedy launch site 25 degrees toward the east—while the Agena's orbit remains fixed in space. This problem of the earth's rotation can be minimized by selecting an orbital plane whose northernmost point nearly coincides with the latitude of the Cape. Nevertheless it is still necessary to actively steer and change the azimuth heading of the Titan II booster, during its powered-flight phase, to make the planes of the two orbits coincide.

The period of revolution of the Gemini spacecraft around the earth, along its inner elliptical orbit, is about 1½ minutes shorter than that of the Agena target. This difference gives the Gemini—the "chaser" vehicle—a 5½-degree-per-orbit "catch-up" rate on the target.

The spacecraft's launching is so planned that the Gemini will be about 20 miles behind and 20 miles below the Agena after 3½ orbits (when it has swung out to its apogee for the third time, about six hours after launch). In this relative position, the Gemini now turns on its spacecraft propulsion and "circularizes" its hitherto elliptical orbit, at 140-mile altitude.

Rendezvous maneuver begins. The Gemini astronauts start their actual closing-in maneuver from this circular 140-mile-high

orbit. The Agena target vehicle is space-stabilized by an attitude-control system employing gyroscopes and little thrusters. It displays a flashing light, easily detected against the star background.

The Gemini's pilot has two control sticks, one in each hand. They activate little thrusters—midget rocket engines of 25 to 100 pounds' thrust apiece. In airless space, these provide the vital control forces that an airplane gets by deflecting its aerodynamic control surfaces.

By moving one of the sticks, the Gemini pilot can point the nose of the spacecraft up or down, and turn it left or right. With the other stick he can move the entire craft up or down, shift it sideways, or push it forward or backward.

Using this manual control, the Gemini pilot brings his spacecraft closer to the target, which all the time is flashing its light in the sky ahead of him and above him. By preventing the flashing light from drifting up, down, or sideways with respect to the star field, he keeps his own craft on a "collision" course with the target.

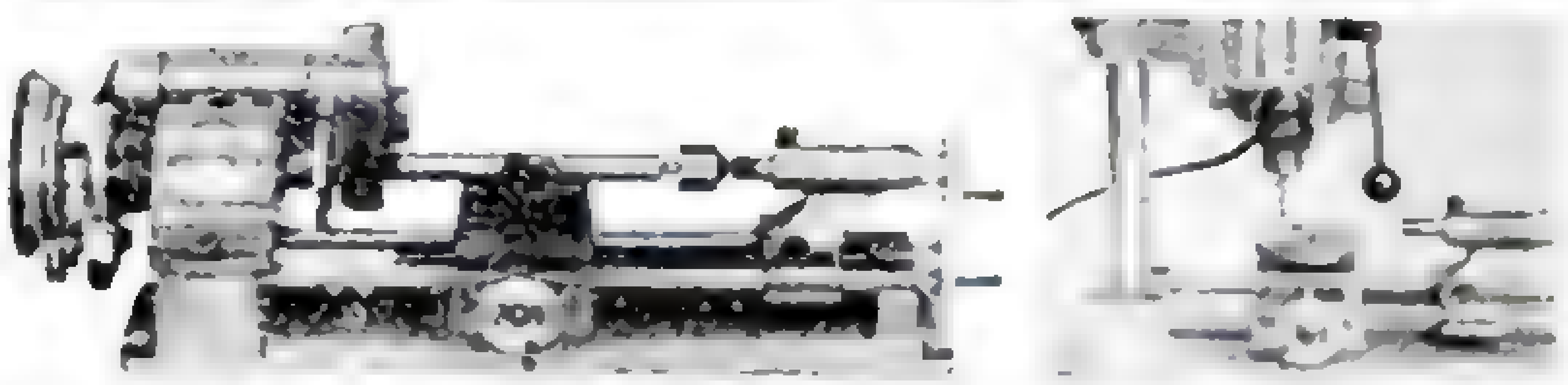
The Gemini's on-board radar keeps him informed of the remaining distance to the Agena, and the closing rate (relative approach speed). As the distance diminishes, the Gemini's excess speed is reduced.

About 20 minutes or so after initiation of the closing-in maneuver, the two vehicles will be within a quarter of a mile of each other, and the relative velocity will have been reduced to eight or 10 feet a second (about 5½ to seven m.p.h.). From this position the final docking phase begins.

Docking. Windows in the spacecraft provide ample vision to perform the docking manually. The Agena target vehicle is equipped with a "docking collar" designed to absorb shock loads produced by a collision velocity up to 1½ feet a second (about one m.p.h.). The docking mechanism includes a latch that prevents the Gemini spacecraft, on making contact with the target Agena, from breaking loose again.

Once the two vehicles are coupled, the pilot of the Gemini can maneuver the combination as if it were a single spacecraft.

To conclude their mission, the Gemini astronauts will uncouple their spacecraft from the target Agena. Then, using its thrusters, the Gemini spacecraft will back away—and, like earlier Geminis, will return to earth by itself. ■ ■



AUGUST 1965 35 CENTS

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We Built a Home TV Tape Recorder (So can you!)

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ELECTRONIC

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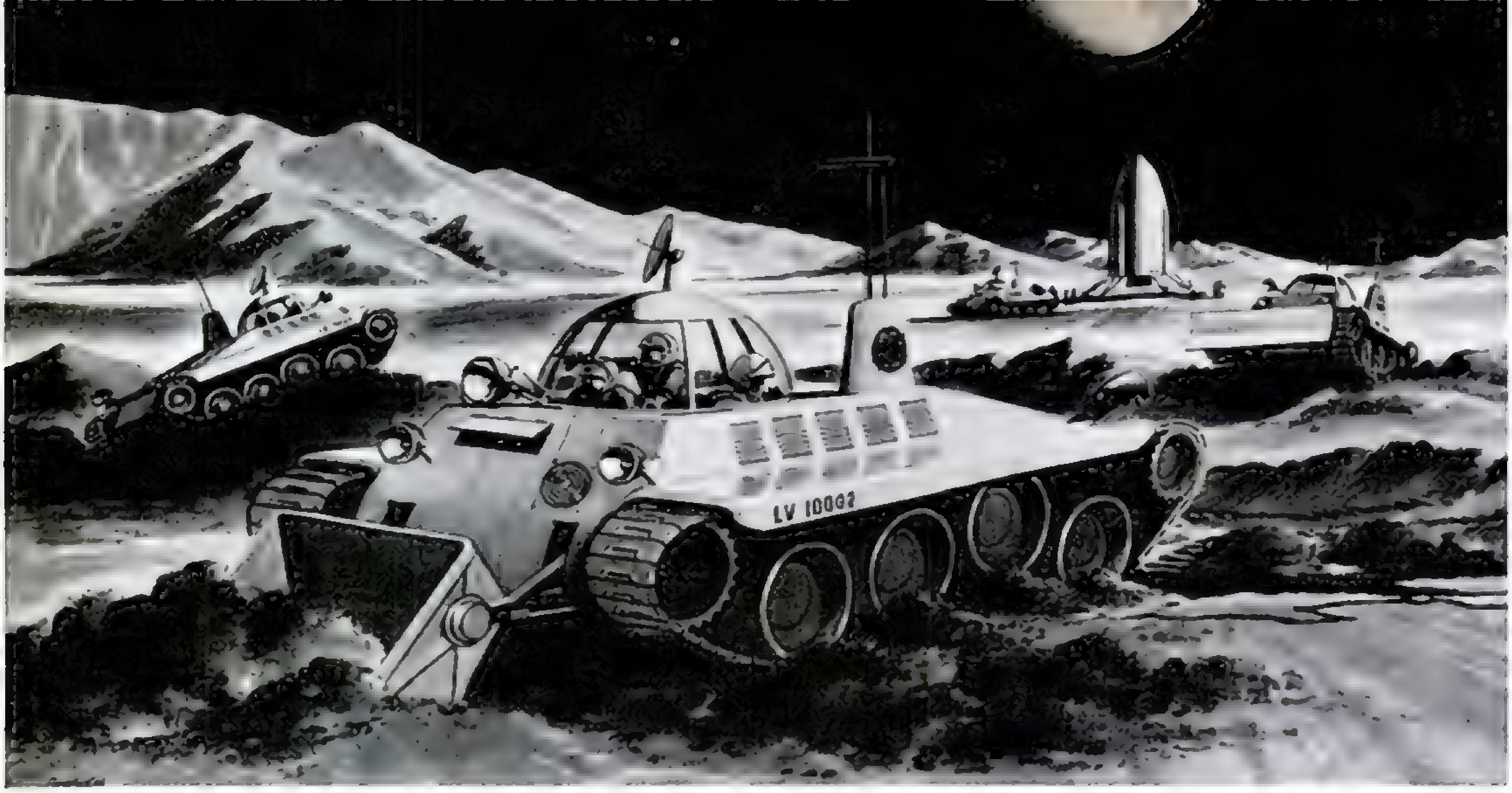


Vehicles powered by fuel cells are pictured constructing a future base on surface of moon.

New advances promise more and longer-lasting—

ELECTRIC POWER

A fuel cell for Gemini, and orbiting atomic batteries and reactors, offer latest ways to put juice on tap in the sky

By Dr. Wernher von Braun

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

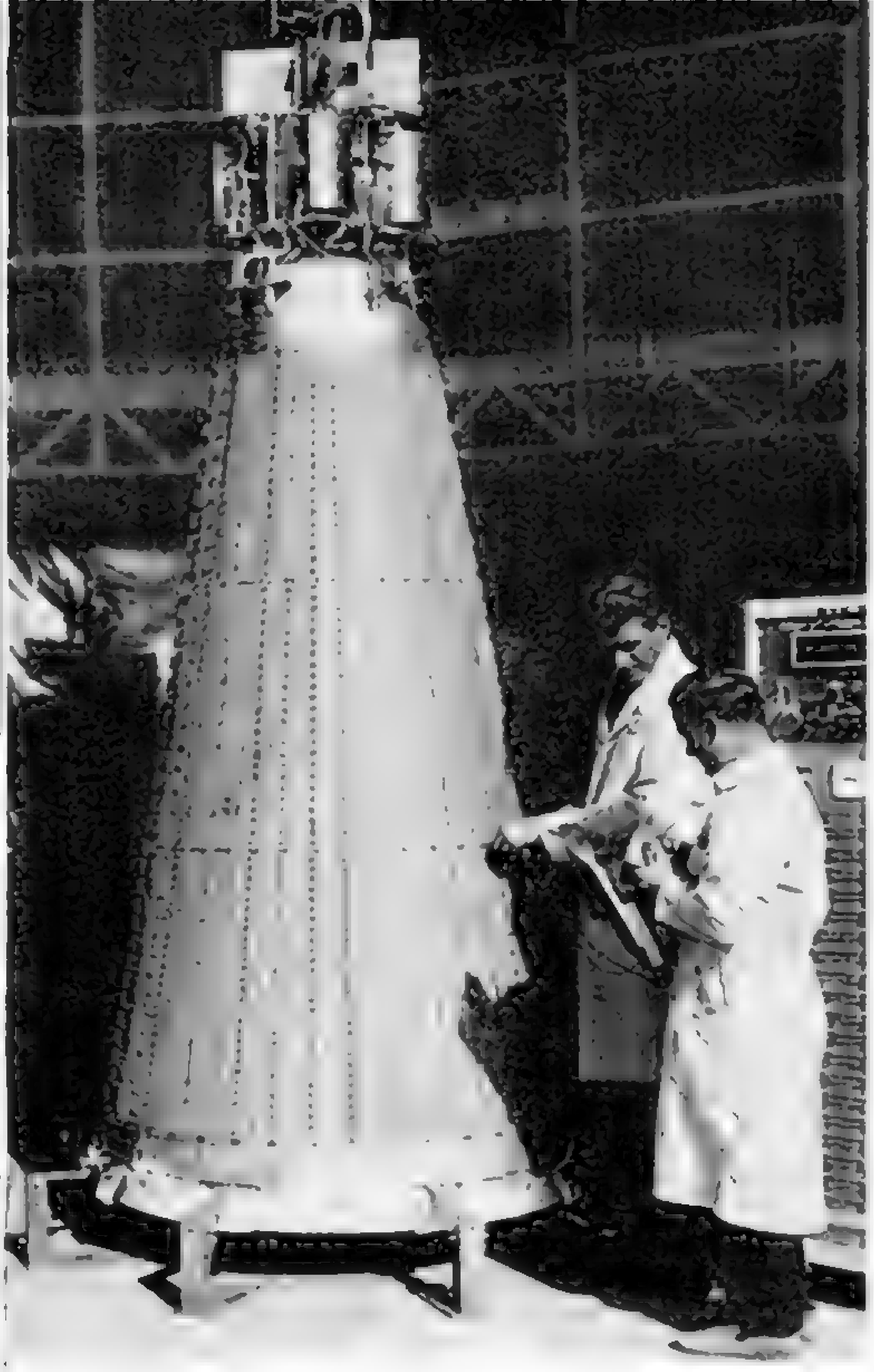
Dr. von Braun, left, outlines to PS Editor Ernest V. Heyn his ideas for coming articles on news-making developments in space science.

A NEW kind of electric-power supply for space vehicles will make its debut in the third manned Gemini flight, due this month. A fuel cell, a novel and promising source of electric current, replaces the silver-zinc batteries that the two-man Gemini spacecraft have used before. Likewise, a fuel cell will furnish electricity in the three-man Apollo spacecraft that will go to the moon.

Space vehicles need electric power, both in rocket-propelled and coasting flight, for all sorts of vital gear: life-support systems, radio, propulsion control, guidance, instruments, and more. Electric power will be required, too, for a lunar base.

Advancing technology offers a widening choice of electric-power sources for space—chemical batteries, fuel cells, solar cells, atomic batteries, and nuclear reactors, to name the more-important ones. Which of these systems will a

Nuclear electric-power sources are long-lived and independent of sunshine or shadow. Atomic batteries like 20-inch-diameter SNAP-9A, above, turn radioisotopes' heat into current for modest power needs of satellites. Higher outputs will come from chain reaction in nuclear reactors, of which the first in space—SNAP-10A, at right—was put in orbit for trial last April.



IN SPACE

space-vehicle designer choose, and why?

Chemical batteries have been a mainstay since the Space Age's beginning. They powered the earliest satellites—Russia's first two Sputniks and our Explorer I. All our manned spacecraft, of the Mercury and Gemini flights, have depended on them. Chemical batteries are still unchallenged as electric-power sources for launch rockets, which demand as much as several kilowatts of power, though for only a few minutes.

Advanced types like silver-zinc and nickel-cadmium batteries offer more power for less weight than the less-expensive lead battery in your car. However, chemical batteries are prohibitively heavy for long use—more than a very few weeks —without recharging.

Fuel cells, while related to chemical batteries in principle, represent quite a radical departure in form. Hydrogen gas and oxygen gas are fed into the tanklike fuel cell. What comes out is an electric current—up to a kilowatt or two. in present designs for spacecraft—and a little water.

A fuel cell thus requires a supply of hydrogen and oxygen, carried along as high-pressure gases or in liquefied form —and can operate only so long as the supply holds out. This gives it a limited life, comparable to that of chemical batteries, for space uses.

For manned space vehicles, however, a fuel cell's attractions are enhanced by the fact that the water it produces is potable. Drinking water must be provided for the astronauts anyway. So it might as well be taken along in the form of hydrogen and oxygen—which, combining in the fuel cell, will generate electricity and replenish the drinking-water dispenser in the bargain.

Fuel cells are attractive for lunar surface vehicles, too. They would make "moon cars" independent of the sunshine

[Continued on page 160]

Electric Power in Space
[Continued from page 59]

required by solar cells, and free of the radiation problems of nuclear power. Water produced by a day's run on fuel cells could be turned back into hydrogen and oxygen at a stationary electrolysis plant, run by solar or nuclear energy.

Solar cells, of which a bank makes up a solar battery, have a theoretically unlimited lifetime. The solar-cell-powered transmitter in our grapefruit-size Vanguard I satellite, launched in 1958, is still operating.

The output of solar-cell installations has grown from Vanguard I's tiny 0.06-watt power to 200 watts in our Mariner IV Mars spacecraft. For higher ratings, they become cumbersome, since a square foot of solar cells yields only a few watts. To avoid this drawback, makers are experimenting with flexible solar-cell "tapes" that can be wrapped around large space-vehicle structures.

Many orbiting space vehicles pass through the earth's shadow at regular intervals, but need a continuous supply of power. Solar cells must then be supplemented by rechargeable chemical batteries. In sunlight, the solar cells supply power needs, and also charge the chemical batteries; in shadow, the chemical batteries temporarily carry the load.

Atomic batteries use the heat given off by the natural decay of various radioactive isotopes, such as plutonium 238, curium 244, or promethium 147. Thermocouples turn this heat into electric current.

An atomic battery called SNAP-9A provides the 20-watt power of one Navy navigation satellite presently in orbit. SNAP stands for "Systems for Nuclear Auxiliary Power," of which a number are being developed jointly by NASA and the AEC for space use.

Radioactive-isotope batteries can supply up to several hundred watts of electricity for periods well over a year. For needs within those figures, they have now become competitive with solar cells.

Besides heat, atomic batteries inevitably emit a certain amount of undesirable radiation, against which a space crew and radiation-sensitive equipment must be shielded. Also, there is a potential hazard, when a spacecraft breaks up during reentry, of scattering radioactive material that will sink to earth, and may slightly raise the radiation level of a surface area. Some

radioisotopes are less hazardous than others, and their use minimizes the risk.

Nuclear reactors provide power, not from radioactive isotopes that decay spontaneously at an invariable rate, but from a controllable chain reaction. This requires an amount of fissionable material, such as uranium 235, exceeding a certain "critical" mass. So a nuclear reactor would not make sense where only a few watts of power is needed, but it becomes attractive once we talk about kilowatts—especially several hundred kilowatts or more.

For example, nuclear reactors will find use in future high-powered TV broadcasting satellites—which, hovering in a "synchronous" orbit, will be capable of beaming TV programs directly into your home set. They will be used, too, in manned planetary vehicles—whose long voyages will call for more comfort, and also for more radio-transmitting power, than is needed in orbiting the earth or in going to the moon. And, speaking of the moon, nuclear reactors undoubtedly will be used to provide electric power for future lunar-base camps.

The first nuclear reactor in space, a 230-pound one called SNAP-10A, was orbited for trial last April. Its flight test proved that such a power plant could be subjected to a rocket launching and then be started and operated in orbit.

In SNAP-10A, thermoelectric elements turn heat from the chain reaction into electricity, and so there are no moving parts. Although SNAP-10A yields only 500 watts, the same thermoelectric principle can be applied to produce up to about 20 kilowatts. Still higher-powered nuclear reactors for space will heat steam or another gas, such as mercury vapor, to drive a turbogenerator.

Choosing a space-power system. How much power is needed, and for how long, obviously will enter into a designer's choice of which system to use. In addition, there is an all-important consideration:

The source of power must be extremely reliable. No single component's failure must ever be permitted to deprive a space vehicle of all its vital power. Hence, just as solar cells, atomic batteries, and fuel cells had to await thorough proof of their reliability before being adopted for use in space, so will other promising innovations in electric-power supply that are still in the experimental stage today. ■ ■

SEPTEMBER 1965 35 CENTS

Popular Science

Monthly

HOW TO KEEP YOUR CAR LOOKING NEW

IMPROVE YOUR HOME! 48 PAGES OF NEW IDEAS:

Cut Your Fuel-Oil Bill up to 25%
Tile Your Own Bathroom
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Lay a Luxury Floor Fast
New Sidings with Built-In Paint
...and lots more

Tiny Electric Eye to Guard Your Home

NEW '66 CARS

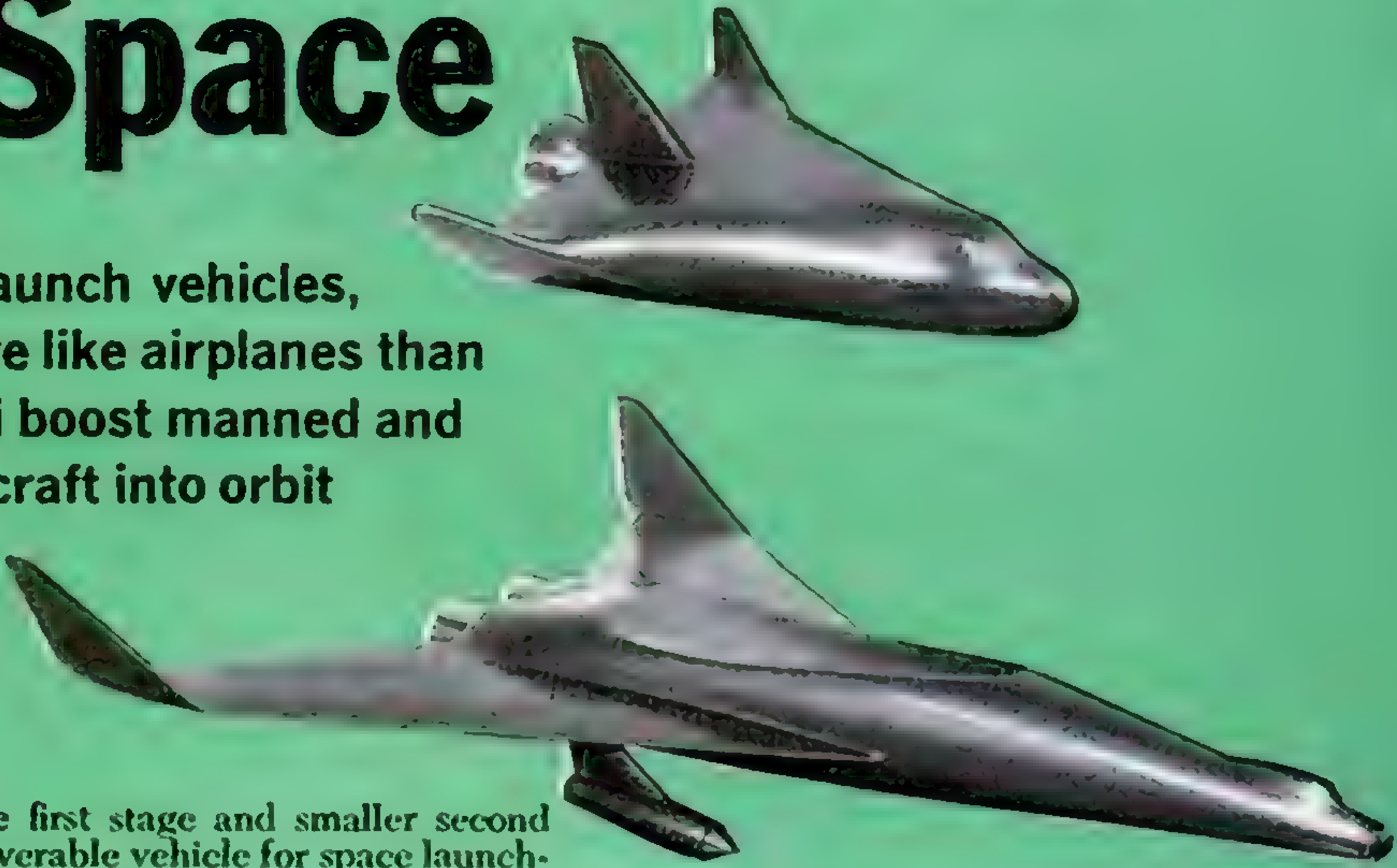
Inside Story on Plymouths, Dodges, and Chryslers

632 I

Jon Lindbergh Works on Ocean Floor

Coming...Ferries to Space

Re-usable launch vehicles, looking more like airplanes than rockets, will boost manned and unmanned craft into orbit



Models illustrate first stage and smaller second stage of the recoverable vehicle for space launchings that the author sees ahead.

By Dr. Wernher von Braun

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

IN THE near future, we may expect to see spacecraft put into orbit in a new way.

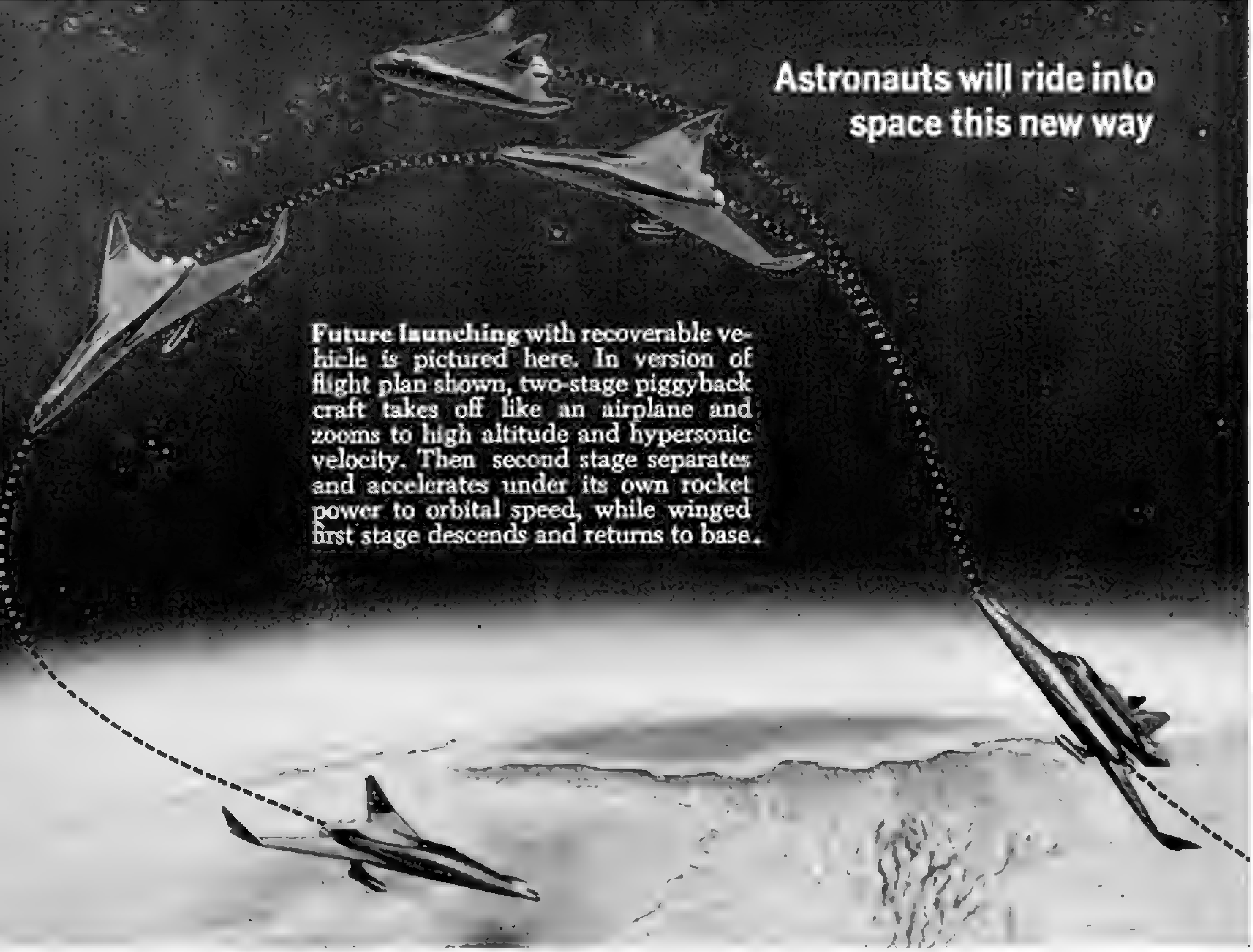
Many of them will be borne aloft by winged and manned vehicles that resemble airplanes more than rockets—and that may even take off horizontally in airplane fashion, rather than vertically like rockets. The most important thing about these radical launch vehicles is that they will return safely to earth, to be used over and over again.

Dr. von Braun, right, attends a briefing at NASA's Manned Spacecraft Center in Houston with its director, Dr. Robert R. Gilruth.

Space flight today is still awfully expensive. Among the biggest items of cost, of course, are the large launch rockets required to hurl manned and unmanned spacecraft into orbit or beyond.

Up to now, all launch rockets have been strictly one-shot vehicles. Whether or not a spacecraft reaches its orbit and performs as expected, the launch vehicle is invariably consumed in the process.

Even with our most advanced launch vehicles, it still costs about $500 to send one pound of net payload into orbit. We must drastically reduce this cost if we are



Astronauts will ride into space this new way

Future launching with recoverable vehicle is pictured here. In version of flight plan shown, two-stage piggyback craft takes off like an airplane and zooms to high altitude and hypersonic velocity. Then second stage separates and accelerates under its own rocket power to orbital speed, while winged first stage descends and returns to base.

to take full advantage of the tremendous potentials of space flight for scientific, commercial, and military purposes. Re-usable launch vehicles will provide a way.

Ferries to space. I think we can expect a re-usable launch vehicle to become available at some time between 1970 and 1975. We can expect such a vehicle to be capable of at least 50 to 100 flights to orbit. There is no reason why it could not make at least one flight weekly. Under these assumptions, we can expect the cost of orbital transportation to drop from the present $500 a pound to $50 a pound, or even less.

In my judgment, for reasons that I shall come to presently, the needs of a suitable design for the first generation of a re-usable launch vehicle point toward a manned craft that will be capable of carrying something like a dozen passengers, plus about five tons of cargo, into a low earth orbit.

What will it look like? Envision an aircraft the size of one of our big jet airliners. This is the first stage of the re-usable launch vehicle. Nestled on its back is the second stage—a smaller aircraft shaped like the space glider of the now defunct Dyna-Soar project, or one of the "lifting-body" configurations under current study. Both first and second stages are manned—the first stage with a flight crew, the second stage with a flight crew plus passengers, if any.

The first stage may be powered either with liquid-rocket engines or with supersonic turbojet engines. If rocket engines are used, it may take off vertically like one of our present-day space boosters—or it may be launched horizontally from a catapult. In the case of air-breathing engines, a catapult-type horizontal launch is mandatory.

A rocket-powered first stage would ac-

[*Continued on page 206*]

Coming . . . Ferries to Space

[*Continued from page 69*]

celerate to about Mach 6 before letting the second stage go. After staging, it would descend into the denser atmosphere, while turning around 180 degrees and slowing down. At a proper altitude and speed, a set of cruise jet engines—hitherto retracted into the body or wings—are lowered to drive the first stage back to the launch base. Meanwhile the rocket-powered second stage has gone on into orbit.

In the case of an air-breathing first stage, staging is likely to occur at a speed not exceeding Mach 3. To make orbit from this lower initial speed, the rocket-propelled second stage must carry more propellants, and thus be larger. On the other hand, the first stage can return to base with the same set of engines used for the boost phase.

For the orbiting second stage to return to the launch base, it is only necessary to wait for the earth to roll around. Just as with Mercury and Gemini flights, the retro-maneuver in orbit must be initiated at a time when the launch base moves into the area where the reentry flight path will terminate.

An "orbital transport" vehicle such as this could serve, for one example, to carry men to and from orbiting space stations, and to replenish the stations' supplies—as well as to carry out a great variety of other missions in space.

What are we waiting for? There are no insurmountable difficulties in designing and developing a re-usable launch vehicle, on the basis of presently available technology. We need not wait for any great breakthrough in scientific research to come up with quite an attractive design.

In this respect, things are comparable to the much-discussed "SST," the Supersonic Transport: While competitive studies, aerodynamic refinements, and engine advances will undoubtedly continue to improve the economic aspects of that future supersonic airplane, nobody doubts the basic feasibility of the project.

But, in another way, there is an important difference between the two projects. A worldwide airline system, served by subsonic jets at the present time, already exists. Marketing planners for the SST know that as soon as the first airline puts a supersonic transport in operation on one of the heavily traveled long-distance routes, all other carriers flying the same route must follow suit

CONTINUED

or close down. Thus the planners can clearly foresee, even today, the potential sales volume for the SST—and they have a fairly reliable basis for comparing development cost with expected or, at least, hoped-for sales.

Unfortunately, our crystal ball for the future sales volume of re-usable space launch vehicles is not nearly as clear.

To be sure, there is plenty of space traffic. Between Jan. 31, 1958, and March 31, 1965, the United States launched no less than 287 rockets into space, of which 222 were successful. But the payloads of these rockets varied widely, from only a few pounds up to more than 10 tons. The space routes ranged from low orbits, barely skimming the outer fringes of the earth's atmosphere, to interplanetary trajectories grazing our neighbor planets.

A multipurpose launcher needed. Before we can set out to spend a billion dollars or more to develop a re-usable launch vehicle, we must seek for it a many-purpose capability that will satisfy at least a major portion of our space-transportation needs for the next decade or so.

The particular launch vehicle that I have described exemplifies such a "common" design—and the reasoning leading to it goes something like this:

Just like airliners, which make no money while sitting on the ground, re-usable launch vehicles must be kept flying—the more, the better.

Now, we have every reason to believe that the greatest number of space flights—manned and unmanned—will be conducted in low orbits around the earth. These are the most economical orbits to attain. They offer the best vantage point for observations of the earth. And they are just as effective as any higher orbit for most astronomical, astrophysical, and other scientific studies to be conducted in space.

The kind of space "business" beyond the moderate payload capability of the re-usable launch vehicle described here must be expected to be of rather low traffic density for the next decade or so. For such more-demanding missions—with very heavy payloads, or leading to destinations much farther away from earth—nonrecoverable launch vehicles, like the Saturn V rocket developed for the Apollo lunar landing program, are likely to continue to be a better bet for years to come.

OCTOBER 1965 35 CENTS

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HOW YOU'LL DRIVE 120 M.P.H. —LEGALLY!

1966 CARS: 28 PH

- Our Anti-missile Missiles—Are They Re
- Build Your Own Garden Mulcher
- What Makes Stan Musial THE MAN?

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Tiny Computers Steer Mightiest Rockets

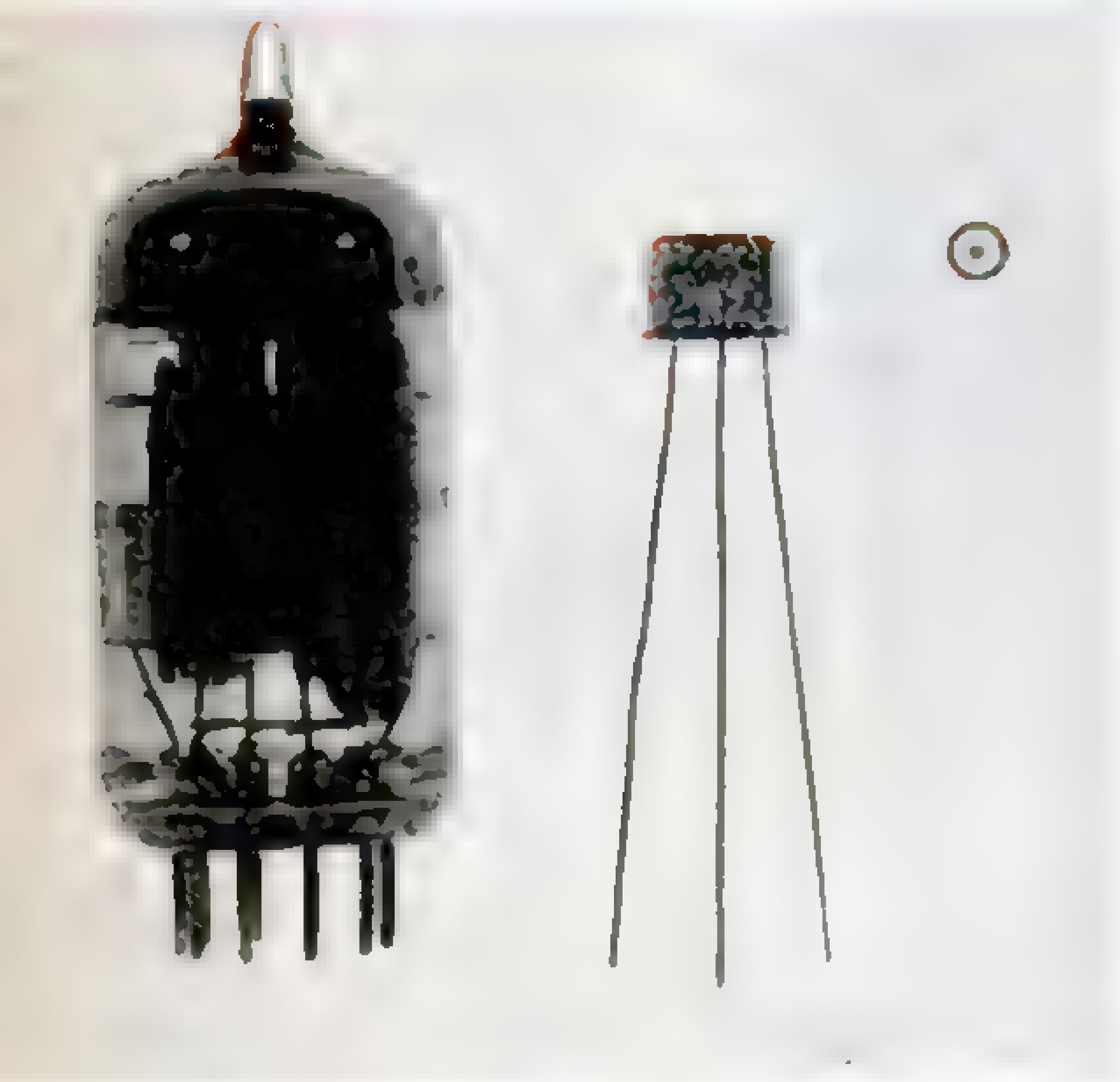
Amazing advances in microelectronics shrink the weight and size of the guidance system for a craft like our moonbound Saturn V rocket—and enhance its reliability in the bargain

By Dr. Wernher von Braun
Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

DRAMATIC progress in the miniaturization of electronic equipment is, without doubt, one of the most important reasons for the rapid advances in rocket and space-flight technology in recent years.

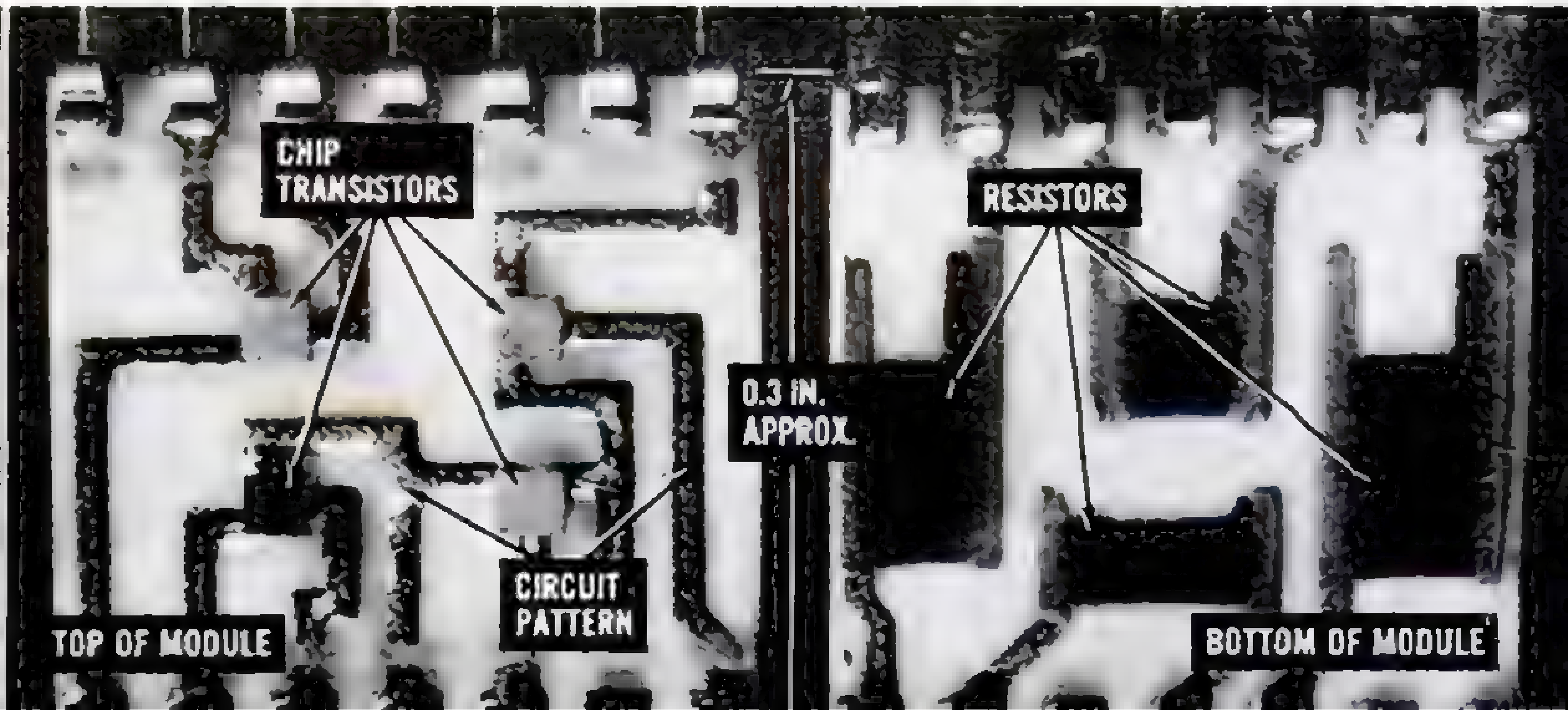
Of course, manned orbital flights would not have become possible without the great strides made in rocket propulsion, new materials, new structural-design methods, advanced hydraulic systems, high-precision gyroscopes, and in other fields. But without the recent contributions of solid-state physics and the resulting technology of microelectronics, most of our achievements in space, whether with manned or unmanned vehicles, could not have come about.

The accompanying pictures tell, better than words, how far the art of miniaturizing electronic components has come. From the vacuum tube, progress has led to the kind of transistor in a transistor radio—and thence, in turn, to the near-microscopic chip transistor or "unit logic device." Many thousands of these ULD chip transistors

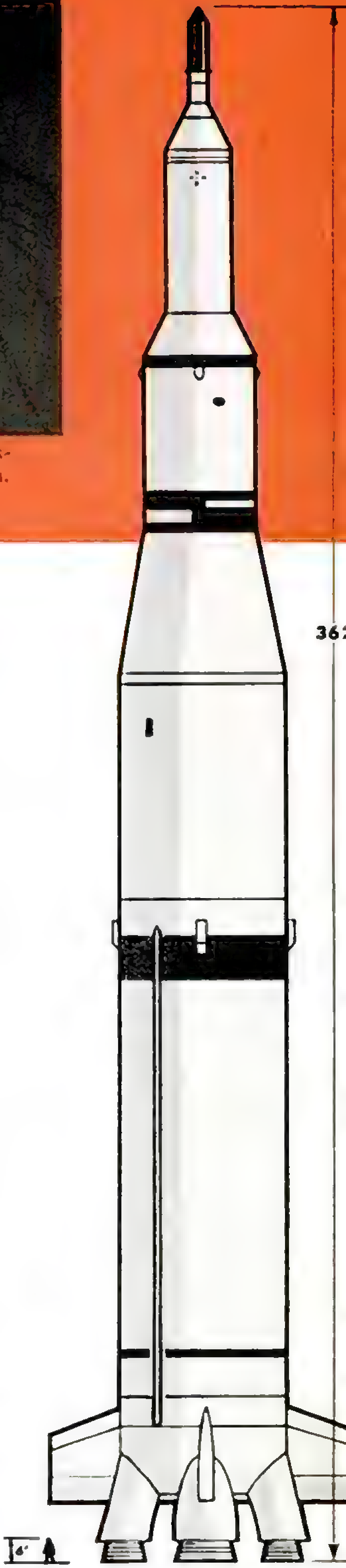


How they compare: Left to right are vacuum tube, transistor that serves same purpose in transistor radio, and chip transistor or "unit logic device" (speck within circle) used in computer for rocket.

Seven chip transistors dot tip of pencil eraser (below, left). Next two views, also highly magnified, show top and bottom of typical IBM module incorporating these "ULD" chips in a microelectronic circuit. Thirty-five of these modules make up a pluggable "page" (view at bottom of opposite page), and 150 such pages go into a rocket's guidance equipment.



Dr. von Braun, left center, tours Manned Spacecraft Center at Houston, Tex., with two of its staff and, far right, astronaut D. K. Slayton.



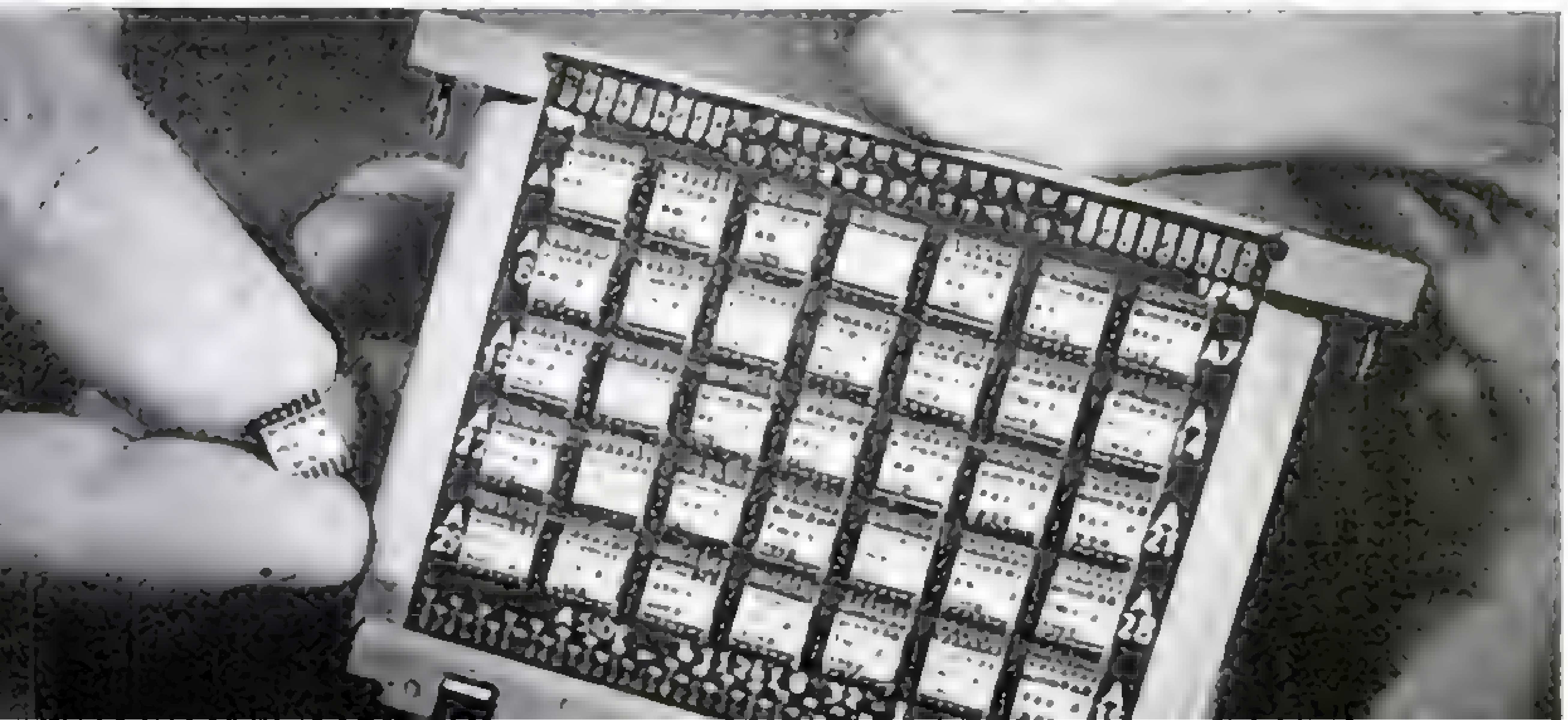
are used in the microelectronic circuits of the guidance computer that IBM is developing for the Saturn V moon rocket.

Shown in the pictures (facing page) is a typical ULD module about 3/10 of an inch square, in which IBM incorporates the chip transistors. They are the squares attached at junctions to the circuit pattern on the top surface of the module. Dark areas, seen on the bottom surface only, are resistors formed by a screen-printing process and then trimmed to the desired resistance. Thirty-five of the modules make up a pluggable "page," and the guidance equipment employs 150 such pages.

Saturn V's guidance computer. The savings in weight and size of an electronic computer based on these design principles are amazing. The Saturn V guidance computer, together with its companion data adapter (which serves as a link between the computer and all other elements of the guidance system), has 80,000 components. It can perform 9,600 operations a second. Its magnetic-core memory has a storage capacity of 460,000 bits (memory elements). Yet the two boxes weigh

[*Continued on page 206*]

For the gigantic Saturn V moon rocket (compared with size of man in NASA drawing at far right), the resulting computer and its companion data adapter occupy two boxes totaling only 5½ cubic feet in volume, 267 pounds in weight, and 438 watts in power required.



Ark., to explore a newly discovered passage. When they didn't return, and searchers found that rain had flooded the cave's main passageway, the team was called in.

Two divers threaded a guide rope through the flooded passageway, then surfaced in an open chamber where the four trapped, shivering men were found. An extra scuba outfit was secured, and the foursome was given instruction on how to use it. Then, one experienced diver in front, one behind, each man plunged, in turn, into the water. Guided by the rope, they swam through the flooded tunnel to high ground near the entrance. By afternoon of the next day, all four were gulping down hot coffee outside the cave.

Karras and other members of the team are ardent cavers, but they are well aware of the hazards. "Caving isn't a dangerous sport," Karras remarks, "but it's growing fast, and many people just don't take time to learn the rules."

Unquestionably, Karras and his team have done much to make the sport safer. ■ ■

Tiny Computers Steer Mightiest Rockets

[Continued from page 95]

only 267 pounds and they occupy a combined volume of only 5½ cubic feet. Almost equally astounding, the two units use a total of only 438 watts, about a quarter as much power as a household electric iron.

But the savings in weight, volume, and power requirement are possibly exceeded in importance by the tremendous inherent reliability of solid-state computers. The Saturn V computer is being built against a specification for a reliability of no less than 25,000 hours' "mean time between failures," and there is every reason to believe that this will be excelled.

A trick greatly contributing to this phenomenal reliability is the generous use of "triple modular redundancy," in connection with so-called "majority-rule voter circuits":

In laying out the design for this computer, IBM identified seven vital functional sections that could cause catastrophic failure of the space vehicle—and where, therefore, computer failures could not be allowed to occur. Then they arranged the computer in such a way that all computational problems arising in these seven critical functional sections are handled simultaneously by sets of three

CONTINUED

exactly similar but independent logic modules, arranged in parallel.

Majority vote decides. The independently derived results are channeled to majority-rule voter circuits that accept "A" as the correct answer as long as two out of the three modules present "A" as their answer. In other words, if one of the three parallel modules comes up with a different answer, it is outvoted by a majority of two to one. The probability of two modules making the same mistake is, of course, utterly remote.

The combination of speed, memory capacity, and reliability of the Saturn V guidance computer and its companion data adapter enables the two units to perform a number of functions that, just a few years ago, would have sounded fantastic. For instance, they provide so-called "path-adaptive guidance."

Perfect Score

To Dr. von Braun and the Marshall Space Flight Center that he heads, our congratulations for a phenomenal score: 10 brilliantly successful launches of the big 188-foot Saturn I rocket, out of 10 tries, in its just-concluded four-year test program.—*The Editors.*

Choosing the best trajectory. Path-adaptive guidance means that as the big rocket climbs into orbit, the computer continuously compares the flight path with the optimum trajectory along which orbital injection may be attained with a minimum expenditure of propellants. It automatically corrects the flight path to follow this optimum trajectory. For example, should one of the five rocket engines of the second stage suddenly quit, the guidance computer would quickly take account of the loss in acceleration—and determine the optimum path to be flown under the power of the remaining four engines.

In addition, the two units help to perform prelaunch checkout, as well as checkout in parking orbit. During the prelaunch period, the computer can perform a self-test and a complete launch-vehicle mission simulation. In parking orbit, it is used not only to recheck the guidance-and-control system, but also the propulsion system of the Saturn V's third stage. In this manner it helps to make certain that the entire space vehicle, after ascending to orbit, is still in perfect condition—so that the Apollo astronauts can safely commit themselves to continue their voyage to the moon. ■ ■

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Popular Science

MONTHLY

Why Can't We Make Cars Safer?

By SEN. ROBERT F. KENNEDY

My Adventures on Wheels

By ERLE STANLEY GARDNER

COMPLETE PLANS: A Lock-Up Workbench That Protects Your Tools

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How We Track Our Spacecraft

At periscope in blockhouse, author views Cape launching.

With telescopes, cameras, and radar, the Eastern Test Range's far-flung outposts speed amazingly detailed news of where a "bird" is heading and how it's doing

By Dr. Wernher von Braun

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

A FEW minutes after a group of spectators see a space vehicle blast off from its launch pad at Cape Kennedy, Fla., the public-address system announces that the spacecraft has been successfully injected into an orbit with a period of revolution of 88.6 minutes, a perigee altitude of 99.6 nautical miles, an apogee altitude of 122 nautical miles, and an orbital plane inclined by 31.73 degrees to the plane of the equator.

A few hours later, this announcement is followed by the most detailed information on stage separation, angle-of-attack encountered in flight through layers of high wind speeds, irregularities in tank pressurization or control voltages, turbopump speeds, structural vibrations, deployment of spacecraft antennas, and many other items of interest.

The tracking and data-acquisition system serving "ETR," the Eastern Test Range, makes this miracle possible. It is probably even more complex than the space vehicle whose performance was just announced. It employs optical, radar, and radio gear to look at, and listen to, the rapidly escaping bird. It involves stations on the American continent, on downrange islands, in aircraft, and aboard ships. It provides radio and cable communication links between all these stations. And it includes a set of timing signals to put all stations on a standard "time base," which is absolutely essential for meaningful data reduction.

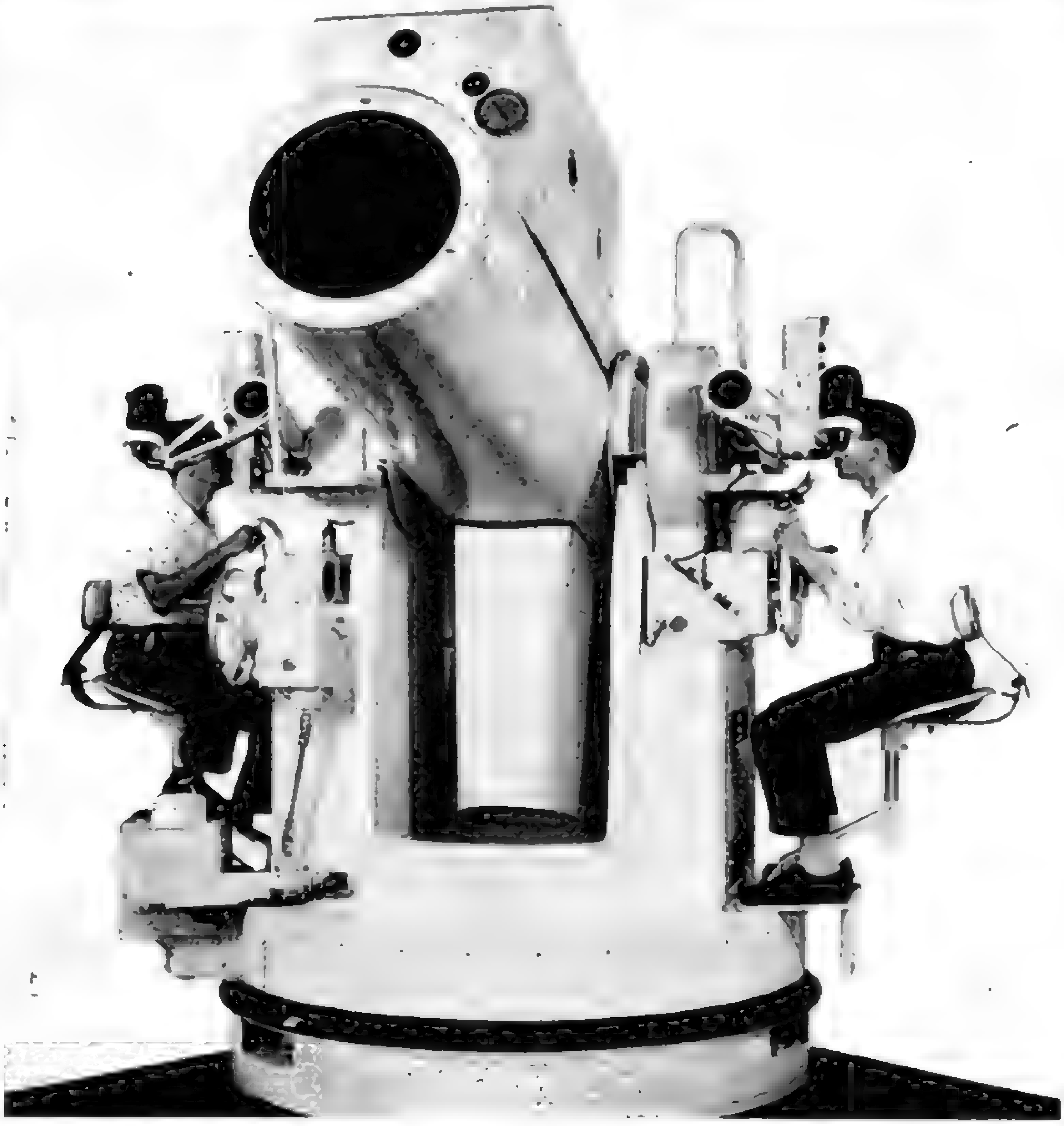
The Eastern Test Range is served by 12 tracking stations. Range Station No. 1, by far the most elaborate, is located at and near Cape Kennedy proper. It is equipped with about everything that has ever been invented and used in this field.

Optical equipment. A particularly important part at the Cape is played by optical equipment because, contrary to the situation at downrange stations, the bird is relatively near. Optical coverage of a launch includes:

- An array of documentary cameras. Their films and still pictures not only serve for formal reporting and public information, but also have played a vital role in analyzing causes of mishaps before or shortly after launch.
- Ballistic cameras, such as the Wild BC-4—an extremely precise still camera using a large, optically flat photographic plate. Several such cameras look at the bird's expected track of ascent from different vantage points. Their shutters are repeatedly opened and closed, simultaneously, by signals from the standard range timing circuit. On each plate the bright trail of a rising rocket appears as a string of beads, whose spacing grows as the rocket gathers speed. By placing the plates in a specially designed

Tracking ships like the Gen. Hoyt S. Vandenberg, seen in Air Force photo, supplement the mainland and island stations of the Eastern Test Range.

Two men at hand wheels operate "Igor" tracking telescope (right) to make long-range photos of the behavior of an ascending rocket vehicle.



Sample photo made with far-seeing "Igor" telescope pictures a striking scientific experiment at 65-mile altitude—a cloud of ice crystals formed when a mighty Saturn I rocket loosed 95 tons of water into the upper atmosphere.

viewing machine, which works on the stereo principle, it is possible to reconstruct the trajectory with very high precision. Ballistic cameras, incidentally, are used at the downrange island stations also.

● Cine-theodolites, such as the Askania Kth 53, a film camera operated by two men simultaneously. One mans the azimuth wheel; the other handles elevation. Both try to keep the bird in the cross hairs of their fields of view. Each film frame photographs the pointing direction of the camera (as indicated on the setting circles in azimuth and elevation) as well as the bird. This makes it easy to compensate for inaccurate alignment and jitter. By placing one frame of the film at a time in a compensator, which permits shifting the image of the rocket back to the picture's center, azimuth and elevation angles are corrected.

● Tracking telescopes, such as the American Optical Company's Igor (Intercept Ground Optical Recorder), pictured in the photograph above. In essence this is a very powerful telescope on a mount somewhat

[*Continued on page 197*]

[Continued from page 109]

like that of an Askania cine-theodolite, but much larger. It can produce high-resolution pictures of far-away events such as separation of the first rocket stage, and ignition of the second.

The downrange stations. Before we come to electronic tracking equipment, let us take a quick look at the Eastern Test Range's 11 downrange stations. Remember, Cape Kennedy proper is Range Station No. 1. About 100 miles to the south, still on the Florida mainland, is Station No. 2 at Jupiter Inlet. Stations 3 through 9 are respectively at Grand Bahama Island, Eleuthera Island, San Salvador, Mayaguana, Grand Turk, the Dominican Republic, and Puerto Rico. Station No. 10, at St. Lucia, has become inactive. Station No. 11 is on Fernando de Noronha, a Brazilian island. And the last of the dozen is on lonely Ascension Island, a British island eight degrees south of the equator and more than 5,000 miles from Cape Kennedy.

Electronic tracking systems. The Eastern Test Range's systems of this kind can be roughly divided into "pulse radar" and "continuous wave" equipment.

Radar tracking is done by aiming a rapid fire of powerful radio pulses at the speeding rocket. The signals are reflected either by the rocket's metal skin ("skin tracking"), or by an amplifier beacon carried in the rocket ("beacon tracking"). The same antenna dish that bundles the outgoing pulse, and aims it at the rocket, collects the returning electronic "echo" and sends it to a receiver. The slant distance from radar unit to space vehicle is shown by the elapsed time between a pulse's departure and return; the line of sight to the bird by the direction from which the loudest echo comes. The Eastern Test Range has a vast array of radar sets, ranging from venerable AN-FPS-16 units to the still-experimental AN-FPS-43. Not all of ETR's radars are used for tracking rockets, however; some (such as AN-FPS-8 units) keep the skies under surveillance for intruding aircraft, or aid the tracking radars in target acquisition.

Using the Doppler effect. Continuous-wave tracking systems are based on the Doppler effect—the familiar phenomenon of a train whistle's drop in pitch as the locomotive passes. A continuous signal of well-stabilized frequency is sent up to the rocket. The speeding rocket receives the electromag-

CONTINUED

netic waves at a somewhat lower frequency, just like a ship running with the waves. As the received signal is radioed back to the ground station, an additional Doppler shift in the frequency occurs.

By comparing the outgoing frequency and the returning one, the ground station can thus determine precisely at what rate of speed the rocket is receding from the station, along the line of sight. By taking this measurement from several locations on the ground, simultaneously, the rocket's flight path can be determined.

Instead of several independent ground stations, however, all continuous-wave tracking systems are using one central transmitter-receiver-evaluator complex, connected to an array of rather widely dispersed antennas that are laid on the ground in a suitable geometric pattern. The system then utilizes the small differences between transmitted and received signals, as noted at the various antenna locations, to learn the space vehicle's flight path.

The Eastern Test Range has the following types of CW tracking systems: Azusa, Mistram, Udop, and Glotrac. All use the Doppler effect; their differences lie in how they utilize the effect for highest accuracy in flight-path determination.

Ships help, too. Orbital flights launched from Cape Kennedy invariably pass over wide stretches of ocean. To assure uninterrupted tracking for critical flight phases—such as powered ascent, or power maneuvers in orbit—the Eastern Test Range operates several tracking ships. Like the land-based stations of the Range, these vessels are equipped with just about everything that can nail down the exact flight path of a space vehicle.

Range ships thus become a vital factor in making space operations effective and safe. In addition to radars and computers, the ships are equipped with an inertial-guidance system similar to those used in nuclear submarines. This unit not only determines the exact location of the ship, regardless of visibility of landmarks or stars, but it also gives a reference for all radar antennas aboard, and furnishes an input on pitch, yaw, and roll motions of the ship during tracking operations. During data reduction, the ship's motions are subtracted from the antenna pointings—with the result that data are, for all practical purposes, received by an antenna on a stable platform.

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Capsules showering from the sky into the sea, for recovery by paradivers, bring back motion-picture films that reveal the full story of our latest launch vehicles' performance during flight

By Dr. Wernher von Braun

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

Ignition of second-stage engines of a Saturn I is shown in photo, made and brought back by capsule.

Rocket-Riding Cameras

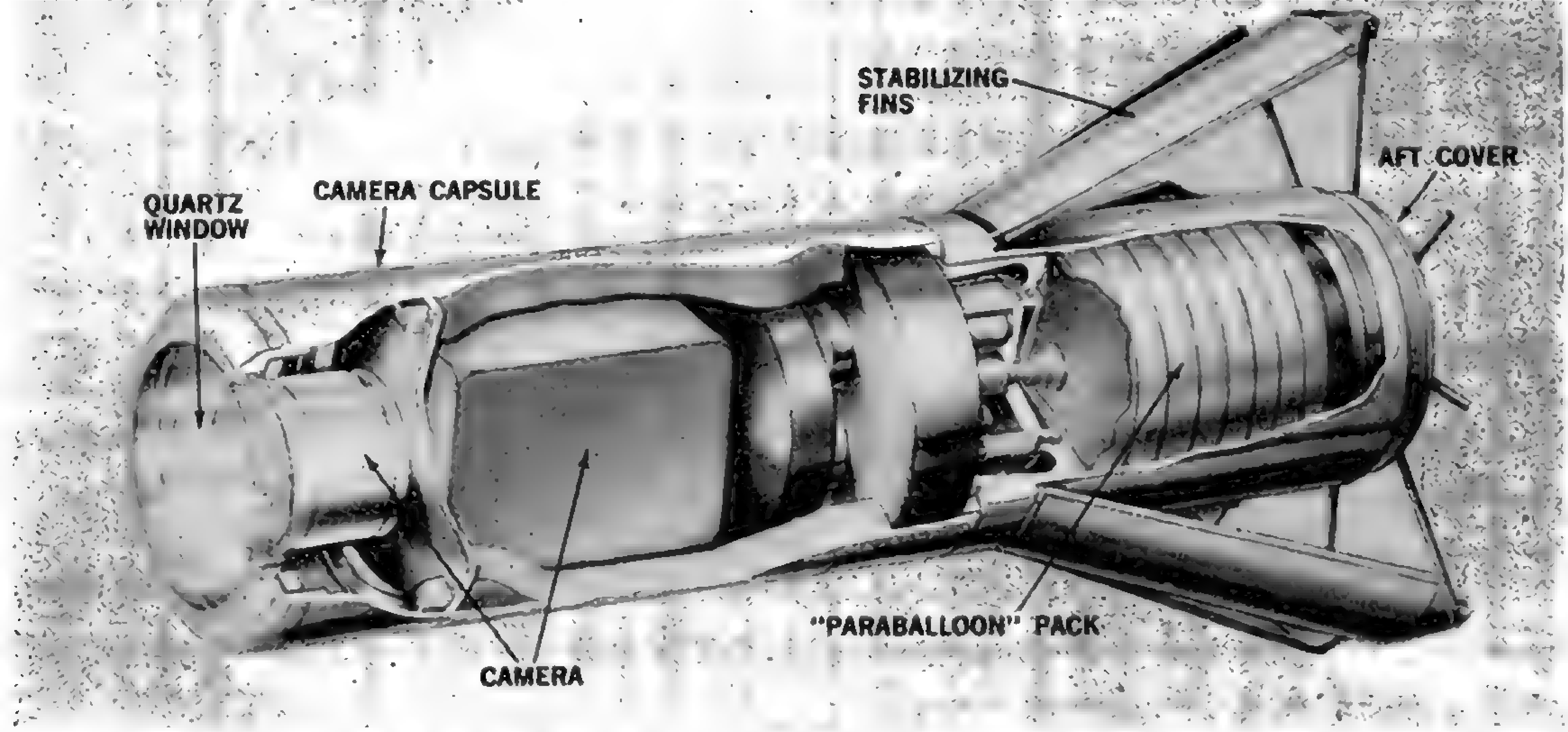
On the morning of January 29, 1964, our fifth Saturn I roared into orbit from Pad 37-B at Cape Kennedy, Fla. Less than an hour after takeoff, the first of eight motion-picture-camera capsules, ejected from the first stage after burnout, were recovered from the sea some 550 miles downrange. Paradivers dropped from planes into the rough water, inflated their rafts, and hauled five of the capsules aboard. Two capsules that could not be retrieved before dark, due to high winds and waves up to 10 feet, were salvaged by a recovery ship guided by flares from the aircraft. When the seventh Saturn I was launched on September 18, 1964, Hurricane Gladys kicked up 15-foot waves in the capsules' impact area and all attempts to recover them were canceled. However, on November 9, two of the capsules were discovered by beachcombers. One had washed ashore on San Salvador Island, the other on Eleuthera. A third capsule was recovered last April by a swimmer off San Salvador. Despite the battering the capsules took, most of the recovered films furnished useful information.

Author is awarded Pioneer of Windrose chain for his initiative in air and space, during a recent visit to Germany.

Because camera capsules enable a designer actually to see what happens in flight, they are proving invaluable in developing rocket-launch vehicles. They offer important advantages over other means, such as telemetry, of reporting a rocket's behavior.

The ejectable motion-picture-camera capsule for the Saturn was developed and tested by scientists and engineers of NASA's Marshall Space Flight Center, supported by the Cook Technological Center in Chicago. The capsule weighs about 60 pounds, has a diameter of 7¾ inches, and is 28½ inches long. There are two different types:

The so-called Model A capsule serves for "direct viewing." It films events visible from the camera's position, before its ejection. At its forward end is a quartz view-



Design of recoverable camera capsule, 28½ inches long, is shown in cutaway view. This direct-viewing model has quartz window to protect its camera from heat of high-speed flight through the atmosphere.

Show How Boosters Behave

ing window that protects the camera lens from aerodynamic heating. Four such direct-viewing cameras, mounted on the front end of the first stage and looking forward, photograph the second stage's igniting and thrusting away from the first one.

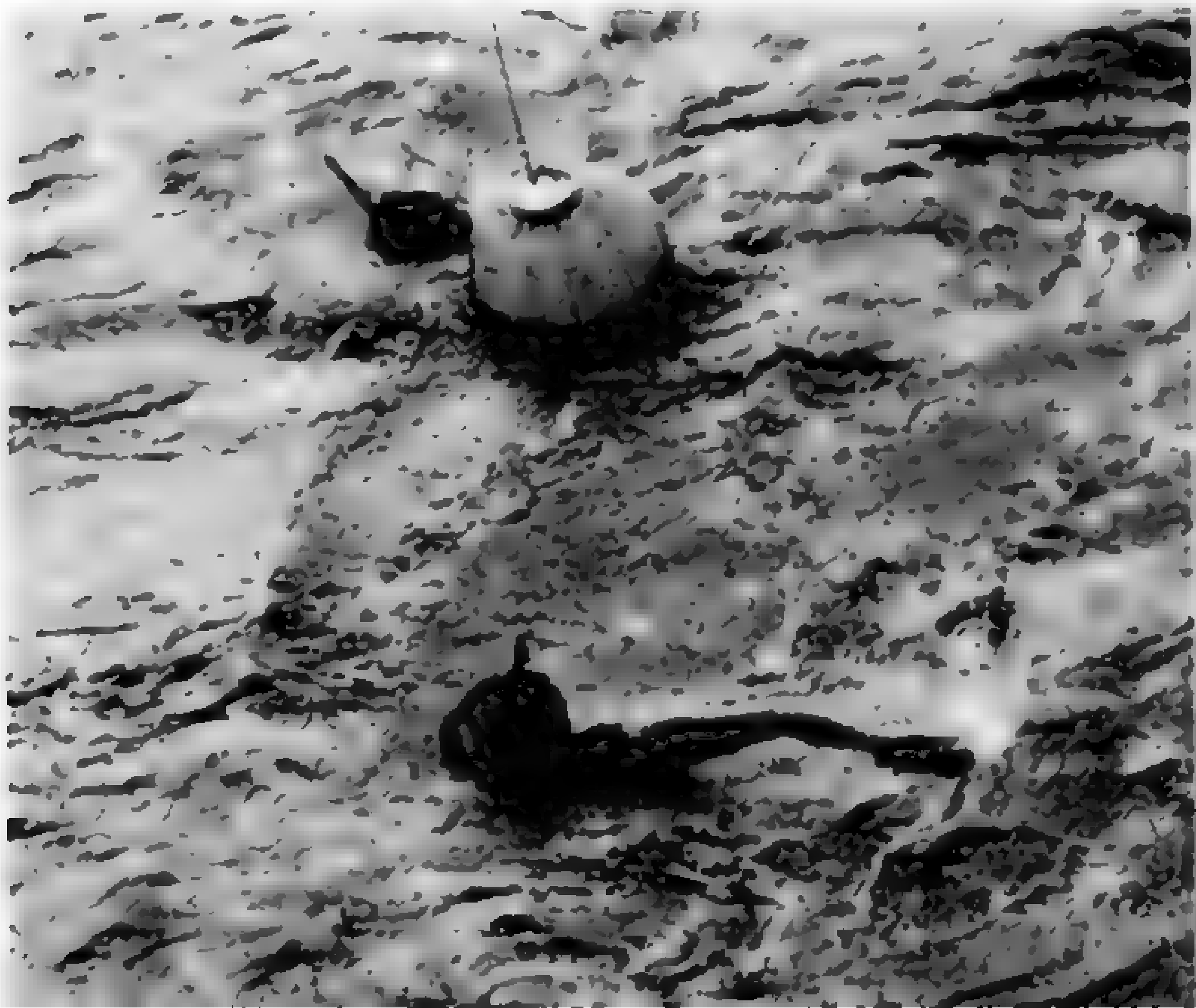
The Model B capsule employs "indirect viewing." The camera lens looks into a "fiber-optics bundle"—to all intents, a flexible metallic hose that permits optical images to be piped around corners. The opposite end of the fiber-optics bundle may be connected, for instance, to the upper bulkhead of the liquid-oxygen tank. The camera capsule then looks into the pressurized tank, just as if peering into a container whose lid has been removed. A special incandescent lamp provides enough light to film events inside the tank.

Essentially the fiber-optics bundle consists of several thousand glass fibers, each

[Continued on page 184]

Paradiver retrieves capsule bobbing in rough sea after its ejection from our fifth Saturn I rocket.

Salvaged capsule, holding precious films of the big rocket's behavior, is handed aboard recovery ship.



Rocket Cameras Show Booster Behavior

[Continued from page 107]

about as thick as ordinary knitting yarn. The body of each glass fiber is transparent; its surface is mirror-coated. Therefore a light beam entering the fiber at one end will be mirrored down the fiber and emerge at the other end, no matter how the fiber is bent or twisted. So, when an optical image is cast on a raster of thousands of front ends of parallel-bundled fibers, the same image will appear on a raster of correspondingly oriented rear ends.

The capsules are ejected when the Saturn I booster is traveling at about 8,400 feet per second (roughly, 5,700 m.p.h.). This is done by catapulting the capsule out of a tube, with the help of pressurizing nitrogen gas. Immediately on leaving the catapult tube, the capsule extends spring-loaded flaps for aerodynamic stabilization.

Each capsule contains a "paraballoon"—an inflatable sphere, with a parachute-like drag skirt attached. At an altitude of 14,000 feet, an aneroid switch causes the bladder of the paraballoon to inflate with pressurized nitrogen. The expanding bladder's pressure, severing shear screws, detaches the entire aft cover (including the stabilizing fins) from the capsule.

Continuing to inflate, the paraballoon reaches its full 18-inch diameter. The combined drag of balloon and skirt slows the falling capsule to a terminal velocity of about 100 feet per second (68 m.p.h.), the speed at which it strikes the water. The inflated paraballoon provides enough buoyancy to keep the capsule afloat.

Advantages of camera capsules. Why are recovered film capsules so valuable? The answer is found in the fundamental difficulties faced by every rocket designer.

A developer of a new aircraft can learn how his brainchild behaves and handles from the test pilot. Built-in flight recorders provide further data. And test flights can be repeated, barring a serious accident, until both the designer and the test pilot are happy with the results.

A developer of a space-launch vehicle is in a less enviable position. His large rockets cannot be flown back to base. While his vehicles are still in the experimental stage, he must equip them with artificial eyes and ears—and see to it that he can evaluate, on the ground, what those eyes and ears see and hear during a flight.

The traditional way to get data in flight has been telemetry. But radioing such information as pressures, temperatures, and voltages to the ground has limitations.

During the development of the Saturn I launch vehicle, for instance, we wanted to know how the second-stage engines ignited, and how the second stage separated from the spent first stage. We wanted to find out, too, whether or not the first stage's oxygen tanks were properly designed to permit complete emptying. Did a vortex, such as you see when a bathtub drains, let pressurizing gas enter the liquid-oxygen feed line prematurely—before the liquid level neared the bottom of the tank? Telemetry is not too well suited to answer such questions. It takes artificial eyes to see what goes on in stage separation—and whether a vortex develops in that LOX tank.

In some cases rocket designers have successfully used small television cameras—but this has limitations, too. During the stage-separation sequence, small solid retro-rockets retard the exhausted first stage; the second-stage engines are ignited; and small solid "ullage" rockets settle the liquid propellants on their tank bottoms. These fire-spitting operations interfere with telemetry or TV communication between rocket and ground, at this vital phase of a flight.

It is in such situations that ejectable motion-picture-camera capsules prove their worth—and justify the effort needed to find them and fish them from the sea.

Built-in recovery aids. To help in locating and retrieving it, a camera capsule provides these features:

- A small radio beacon, on the upper part of the paraballoon, enables aircraft and ships to home in on the floating capsule.
- A high-intensity light beacon, flashing 20 times a minute, aids night recovery.
- A dye marker colors the surrounding water green with a fluorescein dye—an aid of proven value for daylight recovery.
- The painted pattern of the paraballoon contributes to safe recovery. Alternating white and day-glow orange panels, above the waterline, give high visibility. The hemisphere below the waterline is a dark purple, to be least attractive to nosy fish.
- A shark repellent of proven effectiveness, cupric acetate, is released into the surrounding water. It prevents the paraballoon—and the paradiver recovering it—from ending up in a shark's stomach. PS

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JAMES BOND'S Weird World of Inventions in "Thunderball" —HOW THEY WORK!

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Story

by MacKinlay Kantor

What Happens to a

Descending like a meteor, the spent first stage of a missile or space vehicle provides spectacular fireworks—and an interesting look at the phenomena of high-speed re-entry

By Dr. Wernher von Braun

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

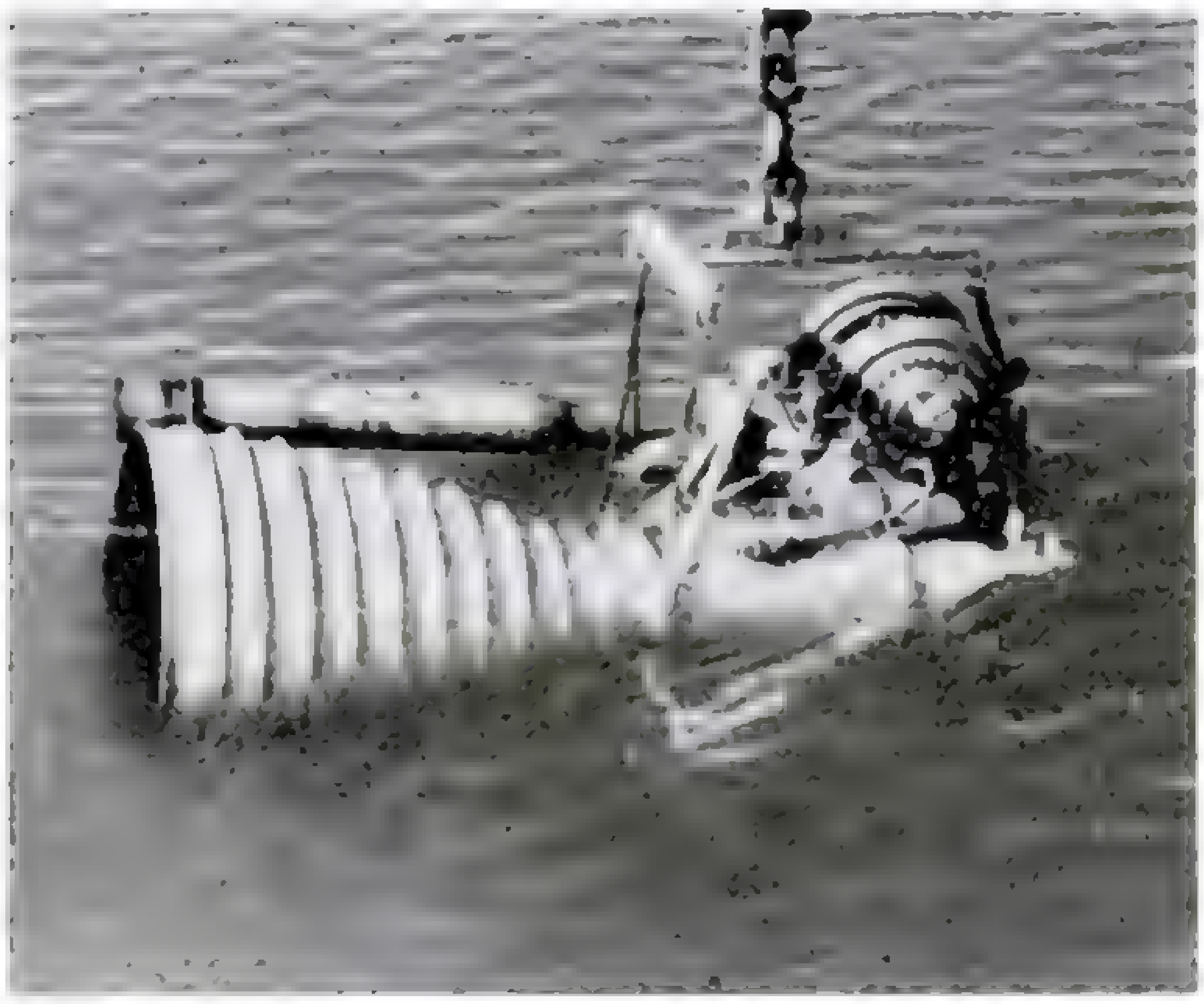
Viewed at night, the burn-up of a rocket missile's booster is a spectacular sight. And the man-made shooting star offers observers an unusual chance to study the phenomena of high-speed re-entry, newly important in this space age.

What happens to a spent booster is an interesting and revealing story. It has many different versions, because of the widely varying velocities at which the re-entry of rocket boosters takes place.

To the best of my knowledge, the U.S. Army's 200-mile Redstone ballistic rocket was the first missile ever to feature separation of the booster from the warhead in flight. For shorter-range missiles, that would be an unnecessary complication and would risk dropping spent stages on friendly troops. Even the German 200-mile V-2 ballistic rocket had no provision for booster separation; its resulting simplification was bought at the price of a rather heavy steel hull for the entire missile, to enable it to withstand the substantial pressure and heat that it encountered during re-entry.

A Redstone booster's story. The booster of the Redstone separates as the boost phase ends and unpowered flight in a ballistic trajectory begins. At power cut-off, a Redstone going for maximum range is speeding at about 3,500 m.p.h., has an angle of elevation of some 40 degrees, and has reached about 25-mile altitude.

Under these conditions, aerodynamic drag on the spent and detached booster is quite small, and it becomes totally negligible in about 10 seconds' more climbing. The booster tumbles slowly—at a rate depending on the lack of symmetry of the kick at separation—as it trails the payload up to the 60-mile-high top of the parabola-shaped trajectory, and then back toward earth.



After sea-dunking test, Jupiter engine still works—but impaired reliability would probably bar re-use.

Some 20 miles short of the 200-mile target, the Redstone's warhead, and the tumbling booster trailing a few hundred feet behind, re-enter the denser layers of the atmosphere. The warhead's nose is kept pointing in the direction of the flight path by a jet-nozzle attitude-control system. Streamlined, arrow-stable, and thus plunging rapidly, the heavy warhead is precisely guided to the target by its inertial-guidance system, which acts on a set of movable air vanes in the warhead's tail.

In contrast, the empty booster, lightweight and tumbling, slows down fast. In less than a minute after re-entry begins, its

Rocket Booster

Re-entry of Jupiter missile, viewed from island of Antigua, makes artificial shooting-star display. Brightest streak is falling booster. Other luminous trails are of instrument compartment and nose cone.

forward speed drops to zero, and its rate of descent to well below the speed of sound. Its end-over-end motion averts excessive aerodynamic heating of any particular spot, and the pressure left in the propellant tanks keeps them from collapsing under the considerable aerodynamic loads. Not weak enough to break up, the booster continues falling toward earth.

The impact. The velocity of the booster at impact—on water, in missile-range firings—may vary between 200 and 400 feet per second (about 135 to 270 m.p.h.). How the booster will strike the water—endwise or broadside—is unpredictable, as it does not assume a steady position in falling.

Boosters have often been found floating in the ocean after impact. While their propellant tanks had not sprung a leak that would sink them, vital parts were so badly damaged that repair and re-use of the boosters was out of the question.

Deploying a parachute before impact would be possible. And drop and seawater-submergence tests have demonstrated the possibility of re-using such elements as the rocket engine. Even so, it is not very likely that boosters recovered from the sea will ever be an answer to our search for economical, re-usable boosters. Recovery and refurbishment of ocean-landed boosters would be costly and involved. More important, the reliability that can be expected of an ocean-recovered rocket will always fall short of that of a fresh-from-the-factory rocket that has passed a tight screen of quality-control inspectors en route. Com-

Continued

parable reliability can be foreseen only from future boosters that can fly back to base under their own power, such as I have described in an earlier article ["Coming . . . Ferries to Space," Sept. '65].

IRBM boosters. For longer-range rocket missiles than Redstone, higher initial velocities are required. Resulting re-entry speeds are likewise higher. An Intermediate Range Ballistic Missile (IRBM) such as the U.S. Air Force's 1,500-nautical-mile Thor or Jupiter has a re-entry velocity in the neighborhood of 15,000 feet per second (about 10,000 m.p.h.).

At such speeds, booster separation no longer is an option available to a designer who wants to gain a little extra missile range, but becomes a *must*. To survive the blazing high-speed re-entry, the warhead must be provided with a special heat shield. Extending this shield over the booster's tankage would make it prohibitively heavy, and would be pointless, since it would not contribute one iota to effect on the target. Thor and Jupiter boosters were therefore detached at booster cutoff and permitted to burn up during re-entry.

In 1958, to learn more about the phenomena of high-speed re-entry, the path of the descending Jupiter IRBM—then still experimental—came under special study. Some 50 miles uprange from the predicted impact point, a Navy-assigned destroyer provided a grandstand view, and cameras and a spectrograph were trained upon the spectacle.

Fireworks in the sky. Visible for about 24 seconds, the meteor-like display perceptibly illuminated the distant ship. The burning aluminum tankage of the booster produced, as expected, a brilliant streak across the night sky—many times brighter than the brightest star and, also, far more brilliant than the luminous trail of the warhead preceding it.

Next morning, however, for all this celestial display, some innards of Jupiter boosters such as compressed-nitrogen bottles and small electrical parts were found floating in the water. Analysis of these parts gave a blow-by-blow account of what happens when a re-entering booster burns up.

At first, only the booster's outside is exposed to aerodynamic pressure and heating. It takes a while to break or burn up the external surfaces—made up of pressurized propellant tankage, and skin structures such as the guidance compartment and the tail structure around the rocket engine. Only then will the booster's interior be exposed to the searing and blazing air stream. And small parts inside the hull may still be shielded from the blaze by additional protective layers.

Take, for instance, the armature of an electric motor within an aluminum "black box," which may also hold other elements of the missile's electrical system. The "black box" undergoes aerodynamic heating only after the surrounding guidance compartment is consumed—which will take much of the total time required to slow the disintegrating vehicle. Heating and melting the aluminum "black box" takes more time—and so, in turn, does the destruction of the motor casing that still shields the armature within it. So the armature may not be exposed to the onrushing air until the booster is moving too slowly for aerodynamic heating to be effective—and may thus survive re-entry without damage.

For boosters of space vehicles, the story is much like that of boosters of short- and intermediate-range missiles. Boosters of two or three stages hurl spacecraft into orbit or beyond—and the various stages drop off at velocities more or less comparable with Redstone and Jupiter separation speeds. One notable exception is the Atlas booster, in the configuration used for the Atlas-Mercury orbital flights.

Atlas' "engine staging." The Atlas rocket does not use "conventional" staging—in which complete rocket stages, including tanks and rocket engines, are dropped off to save weight. Instead, it uses "engine staging." Two "booster" engines are dropped off during ascent, and the flight continues under the power of one "sustainer" engine fed from the same propellant tanks. Thus the re-entry phenomena that we have been discussing apply only to the detached "booster" engines.

The Atlas' entire tankage is carried into orbit. The orbits attained in Atlas-Mercury flights were only about 100 miles up, and decayed after two or three orbits. Since Atlas tankage is made of steel, its chance of surviving re-entry was much higher than that of the aluminum tankage used in most boosters. Parts of Atlas tankage stemming from Mercury flights have indeed been found in Latin America.

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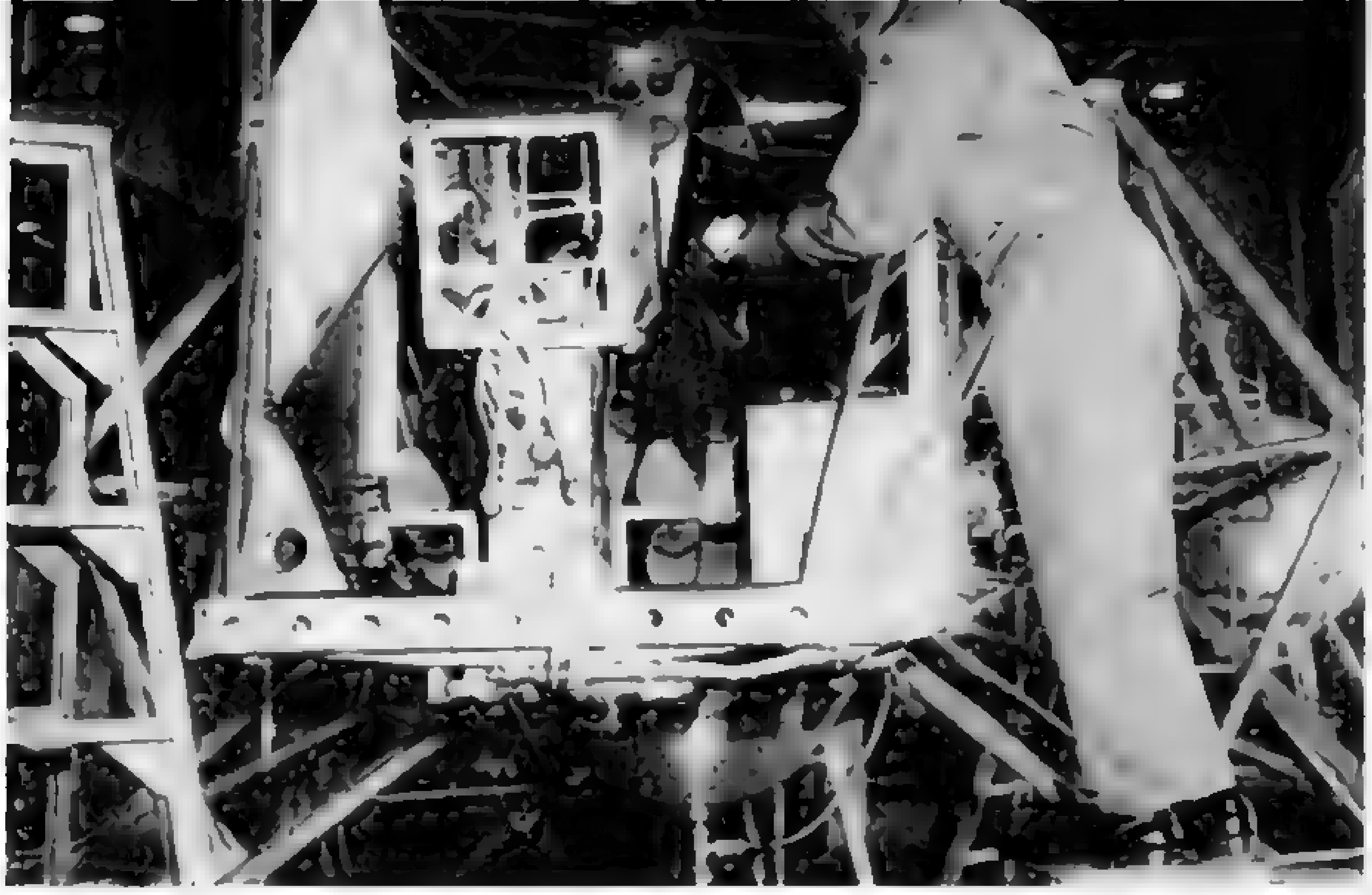


Practicing

Seated at controls of LLRV, Dr. von Braun is shown how they work by Joseph A. Walker, chief research pilot at NASA's Flight Research Center, who was first to fly craft.

By Dr. Wernher von Braun

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

When a report in last November's PS on the LLRV rocket craft was written, the vehicle was still undergoing preliminary flight tests. Since then, these trials have been completed—and actual simulations of moon landings with the LLRV have begun. Here, Dr. von Braun brings up-to-date the story of the strange craft and its purpose.—The Editors.

Long before our first Apollo astronauts descend from a lunar orbit to the moon's surface, they will have practiced this critical maneuver on earth. They will get their training with a strange-looking flying machine called the Lunar Landing Research Vehicle, or LLRV, designed to simulate an Apollo landing on the moon.

Two of these craft were delivered in the spring of 1964 to NASA's Flight Research Center at Edwards Air Force Base, 80 miles north of Los Angeles and right in the heart of the Mojave Desert—a site resembling the moon's barren landscape. By late last year, preliminary flight trials of the vehicles and their equipment were successfully concluded. Now the LLRVs have begun fulfilling their purpose—to help engineers and astronauts familiarize themselves with the down-to-earth problems of putting a manned vehicle down on the moon.

The lunar landing. Since an LLRV is to simulate a lunar landing, let us first examine the tasks it is to duplicate:

In Project Apollo, two of the three astronauts, while in orbit around the moon, will transfer from their capsule, or Command Module, to the Lunar Excursion Module, or LEM. The LEM in essence is a two-stage rocket craft. As it descends from lunar orbit under the power of its throttlable first-stage engine, the horizontal velocity is gradually reduced. At a few hundred feet above the moon surface, the LEM is to hover motionless, while the astronauts select a suitable landing spot.

The touchdown maneuver itself resembles that of a helicopter, with the rocket engines' "thrust-control" lever replacing the chopper's "collective-pitch-control" lever. Shock-absorbing struts on the four legs of the spiderlike landing gear are to take care of the first contact, hopefully soft, with the lunar soil.

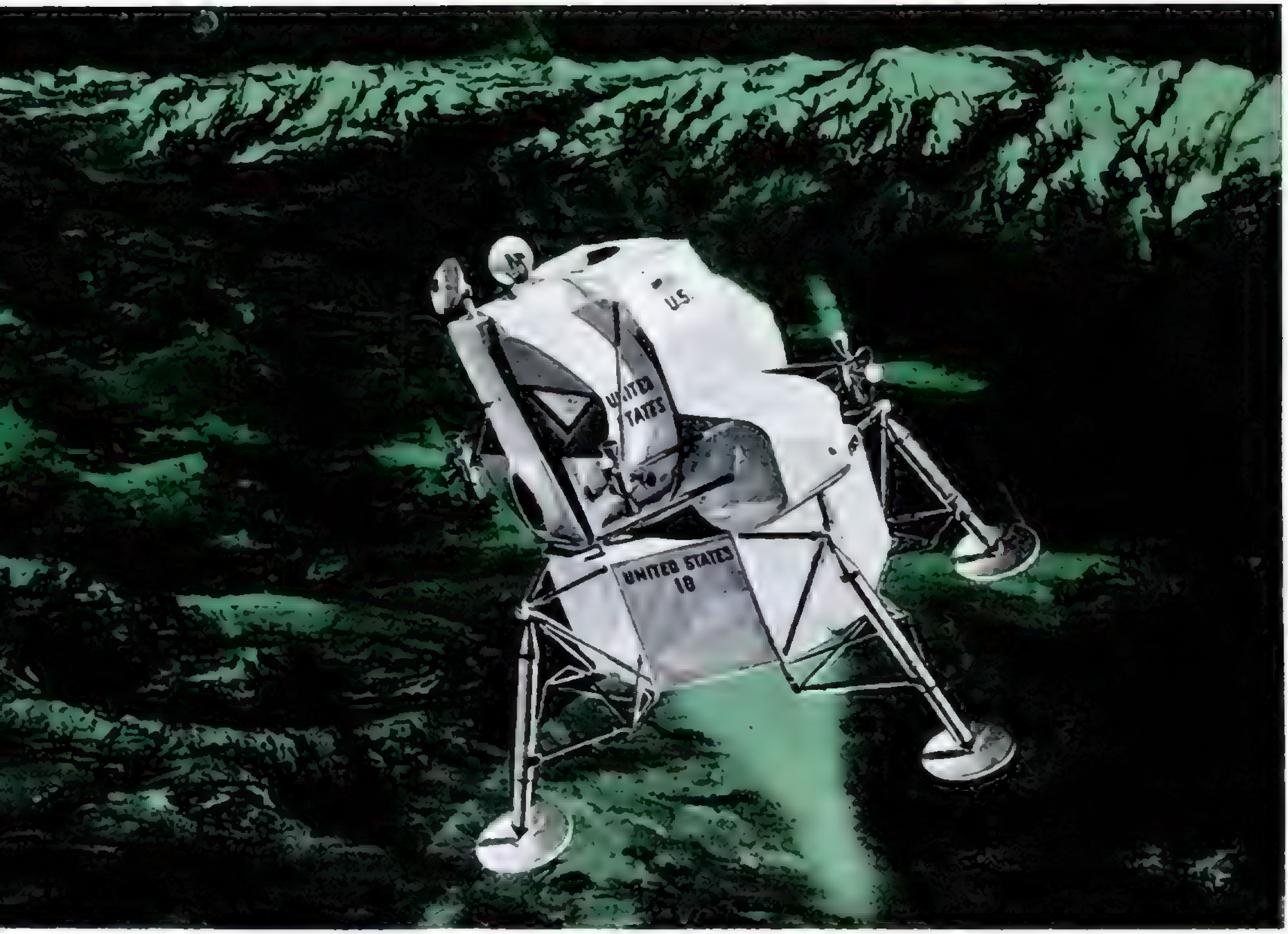
The return trip from the moon's surface to the orbiting Command Module uses the rocket power of the LEM's second stage. The pressurized flight-crew compartment, which has served as the flight deck during the descent under first-stage power, forms a part of the second stage.

The LLRV's task. The Lunar Landing Research Vehicle must do these things:

- Simulate as realistically as possible the terminal portion of the LEM's descent from orbit—say, from 1,000-foot altitude and 40-m.p.h. horizontal speed down to contact with the lunar surface.
- Allow for the moon's weak gravitational pull, only about 1/6 that of earth.
- Take into account the moon's lack of an atmosphere.
- Simulate the initial part of the ascent of the LEM's second stage from the moon.

Flights with a strange rocket-powered craft are showing how our astronauts will touch down safely on the lunar surface

a Moon Landing on Earth



Descent of LEM to moon's surface, above, is simulated by the Lunar Landing Research Vehicle.

• Permit simulation of an "aborted landing" on the moon. If the astronauts decided, a few seconds before touchdown, that the selected terrain did not look suitable for a safe landing attempt, plans would call for immediate return to the orbiting Command Module.

• Provide maximum safety for trainees and vehicles. Specifically, have adequate redundancy so that no failure of a single part could cause a disastrous crash. Also, provide safe bail-out or ejection for the pilot, from all altitudes down to zero.

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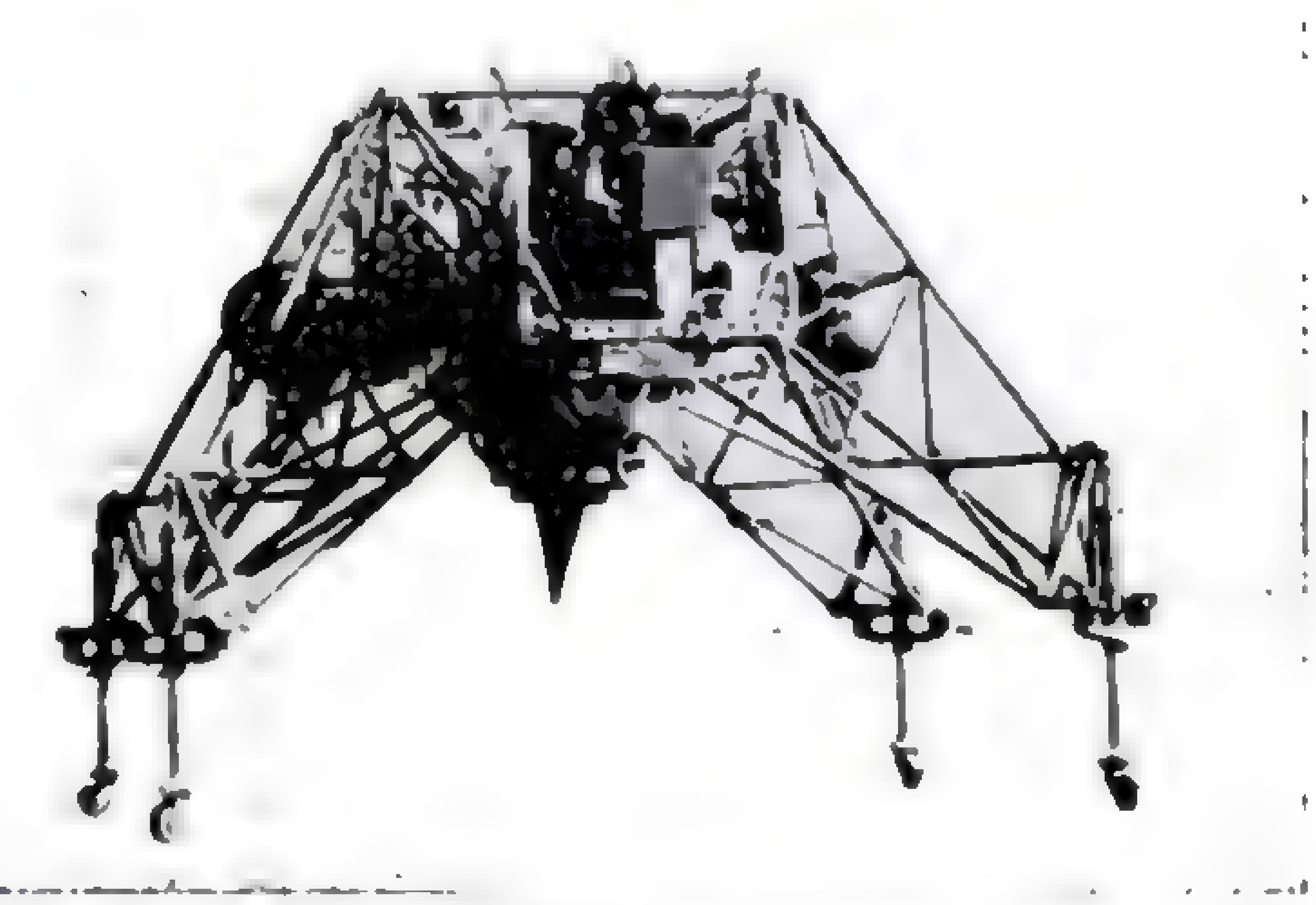


Pictured in flight, LLRV maneuvers above California desert during one of its preliminary trials.

Practicing a Moon Landing on Earth

[Continued from page 99]

These are the specifications that the LLRV's maker, Bell Aerosystems Co. of Niagara Falls, N.Y., has sought to meet. The LEM has often been called The Bug; the LLRV, which simulates its performance, could be called The Flying Bedstead.

Standing 10 feet tall, it has four truss-like legs spreading a little over 13 feet apart. With a full fuel load, it weighs in at about 3,000 pounds.

The open cockpit, a platform about six feet above the ground, extends forward from the main frame between the two front legs. It accommodates a single pilot. His equipment consists of an instrument panel, a side console, three control sticks (two for power, one for pitch-and-roll control), a pair of rudder pedals, an ejection seat, and an oxygen-breathing system to protect him from the thrusters' fumes.

The LLRV gets its lift principally from a vertically mounted General Electric CF 200-2V turbojet engine. This is actually a J85 jet engine with an aft fan attached, increasing its zero-speed thrust from 2,800 to 4,200 pounds. Mounted in a gimbal ring, the engine is gyroscopically kept pointed straight down, even when the craft tilts. To simulate a lunar landing, its thrust is throttled down to exactly five-sixths of the vehicle's weight.

The remaining one-sixth of the vehicle's weight is supported by two throttlable hydrogen-peroxide lift rockets of 500 pounds' maximum thrust each. They are mounted on the LLRV's main frame and tilt with the vehicle. Thus they simulate the thrust of the LEM's single throttlable descent engine. The turbojet engine simply cancels the excess of earth gravity over moon gravity.

Eight little rocket motors, likewise powered with hydrogen peroxide, control the attitude of the LLRV. Each attitude rocket is actuated by an individual solenoid valve of on-and-off type. As in a small plane, the pilot controls pitch by fore-and-aft movement and roll by right-and-left movement of a stick. Foot pedals provide yaw control. Stick and pedals are linked electrically to the solenoid valves.

In this fashion the LLRV duplicates the entire behavior of the LEM—acceleration and attitude changes, and control response—under the true condition of one-sixth of earth gravity prevailing on the moon.

Flying the LLRV. For a lunar-landing sim-

ulation, the LLRV climbs to desired altitude on the power of its turbojet engine alone, with gimbals locked in position. Then, with its nose pushed downward 10 degrees, it is accelerated forward by the horizontal component of the jet engine's lifting force. When the craft attains the desired conditions to begin a lunar-landing simulation—for instance, 1,000-foot altitude and 40-m.p.h. horizontal speed—the jet-engine gimbal is unlocked to let its gyrostabilizer hold it "true vertical," and its thrust is throttled back to five-sixths of the craft's weight.

Since this weight changes as a result of fuel consumption, a simple computer tells the engine exactly what thrust is needed to equal five-sixths of the weight at any moment. Possible wind effects can be offset by a rather sophisticated steering mode. Accelerometers pick up and identify any lateral or longitudinal acceleration that cannot be accounted for by the lift or attitude-control rockets—and that, therefore, must be caused by wind. In response, the gimbal actuators point the jet engine just enough away from straight down to compensate.

For safety, the LLRV has in reserve a standby set of six 500-pound-thrust lift-rocket engines, and a duplicate set of attitude-control rockets. It can fly with either set of each. A 22-foot drogue parachute will help in case of a jet-engine-out landing from a high altitude. As a last resort the pilot can eject—with a catapult-parachute system tested successfully even at ground level—or, given enough altitude, simply bail out.

An LLRV was first flown on Oct. 30, 1964, by Joseph A. Walker, chief research pilot of NASA's center at Edwards. Over the following year, more than two dozen flights, averaging four to five minutes and reaching up to 800-foot altitude, served to check out the vehicle's performance.

With this preliminary phase completed, the LLRVs have now gone into service for practicing moon landings. At this writing, more than 30 simulated lunar descents have been made, in a series of some 150 or more to be performed at the Edwards base—a program that may extend into late summer or fall of this year. After that, the LLRVs may be transferred to the Manned Spacecraft Center at Houston for use by the astronauts in training flights there. ■

MARCH 1966 35 CENTS

Popular Science

MONTHLY

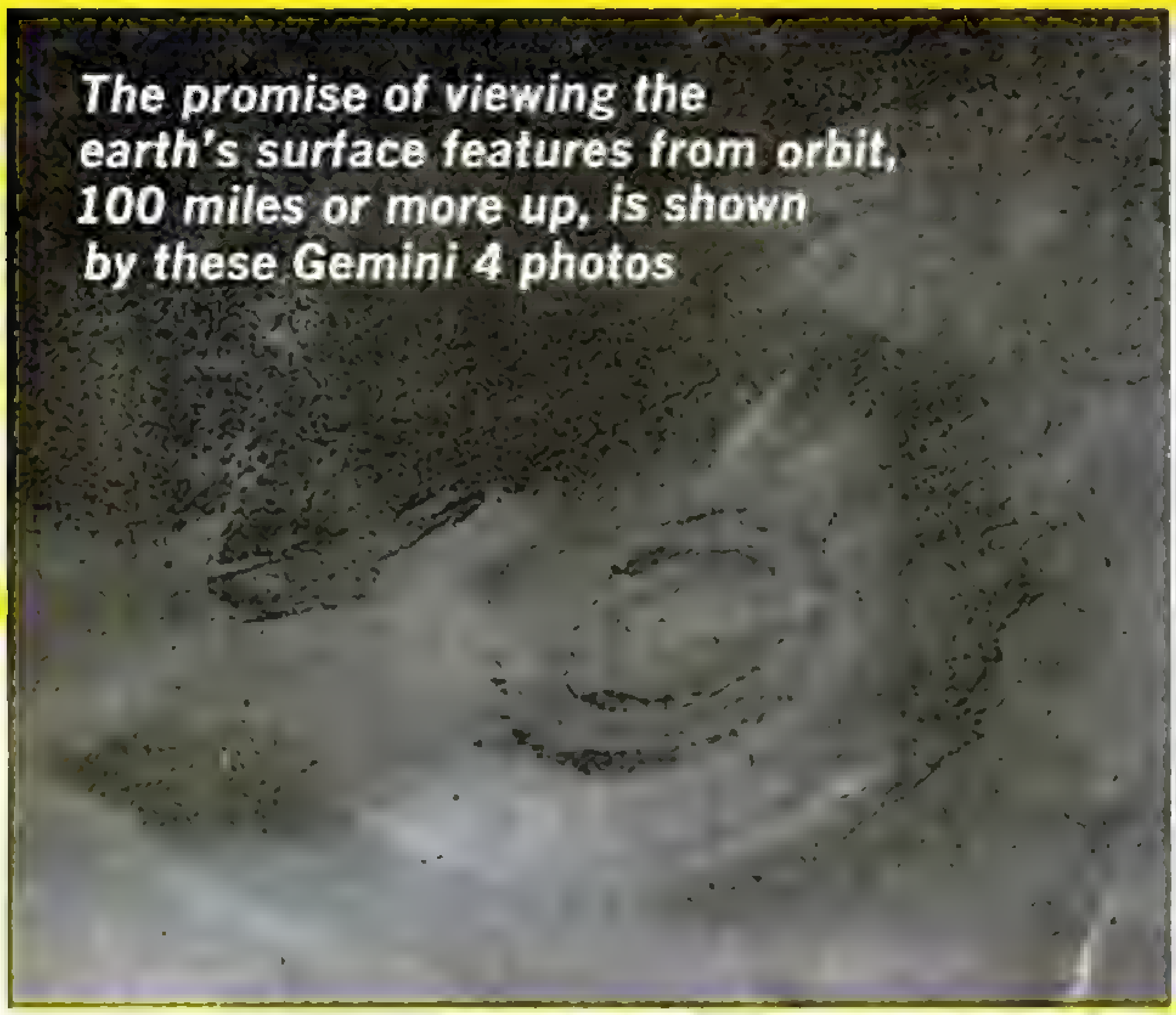
ARE YOUR TIRES SAFE ENOUGH?

The Uproar Over 2-Ply Tires

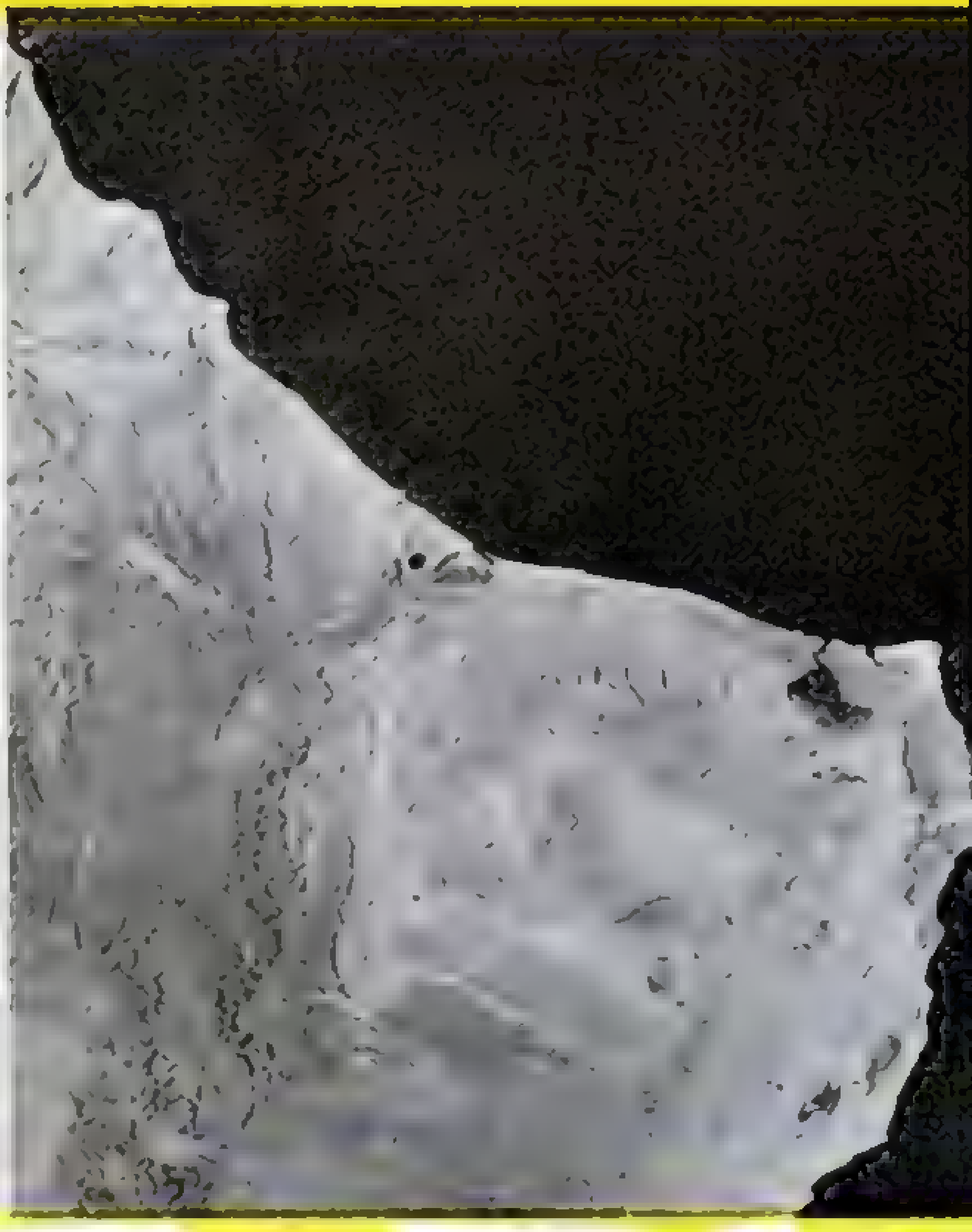
Inside Story of the "Forgotten" F-5

OUR BANTAM SUPERSONIC JET

- How I Search for Lost Gold Mines...and Why By ERLE STANLEY GARDNER
- POWER MOWERS: New Designs Are Making Them Safer
- IN COLOR: Secrets of Wood Glazing



Mystery formation, possibly meteor-made, in Mauritania is eyed from orbit. Such views may aid geologists and prospectors.



Arabian Peninsula's tip is filmed by Gemini 4 with airplane-view clarity.

Bonanzas on the Way

Here are four big ways our Project Apollo-Saturn will pay off—besides its dramatic aim of a manned lunar landing before 1970

By Dr. Wernher von Braun

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

As a nation we are firmly committed, everyone knows, to Project Apollo-Saturn—the plan to land an American on the moon before this decade ends.

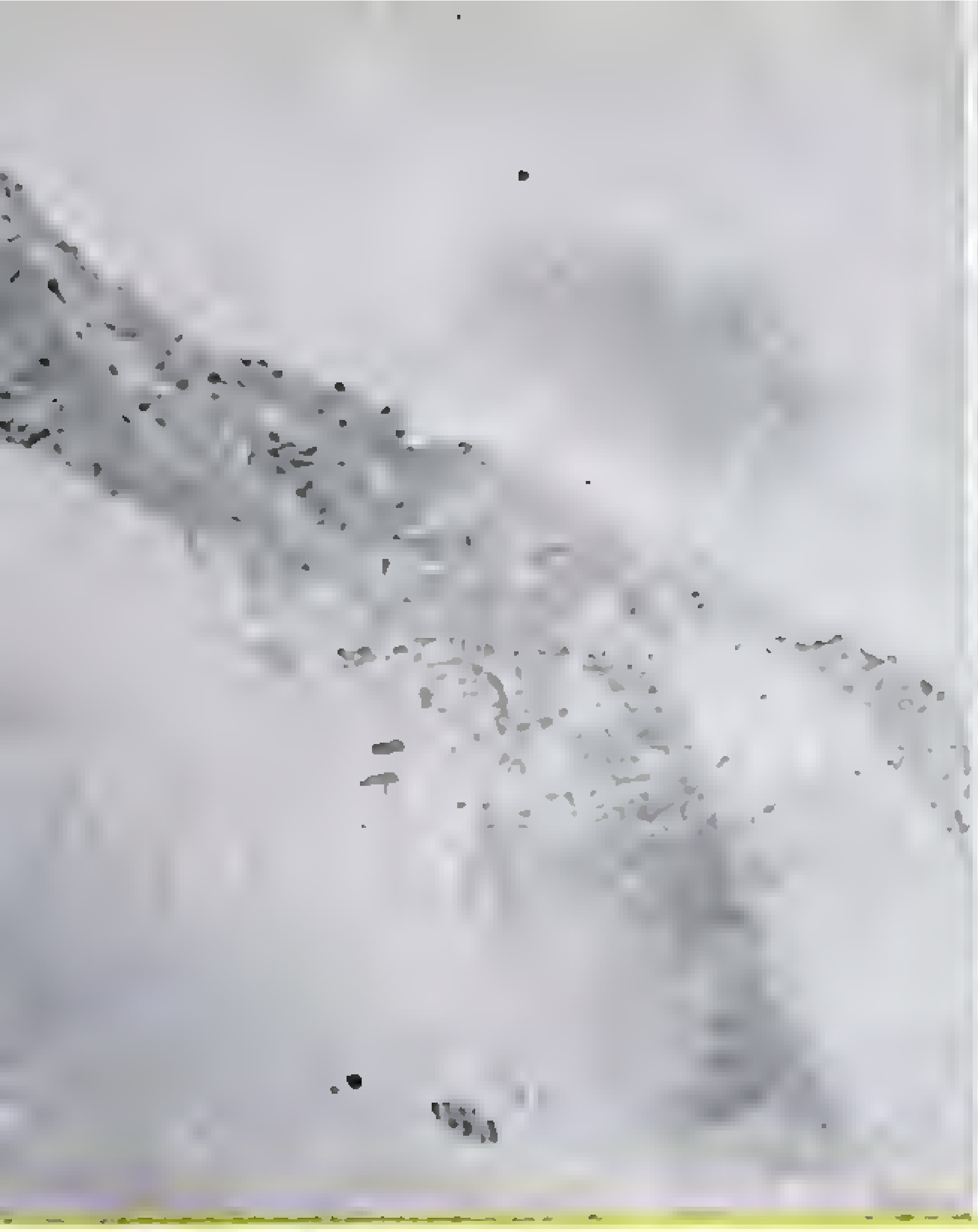
Less well known is the fact that a successful lunar landing in this decade is not so much an end in itself, as a most effective focus for developing a broad U. S. manned-space-flight capability that will pay off in four major ways:

- Direct benefits to all mankind.
- Gains for our national security.
- Fundamental knowledge about the universe and its origin.
- Engineering and managing know-how.

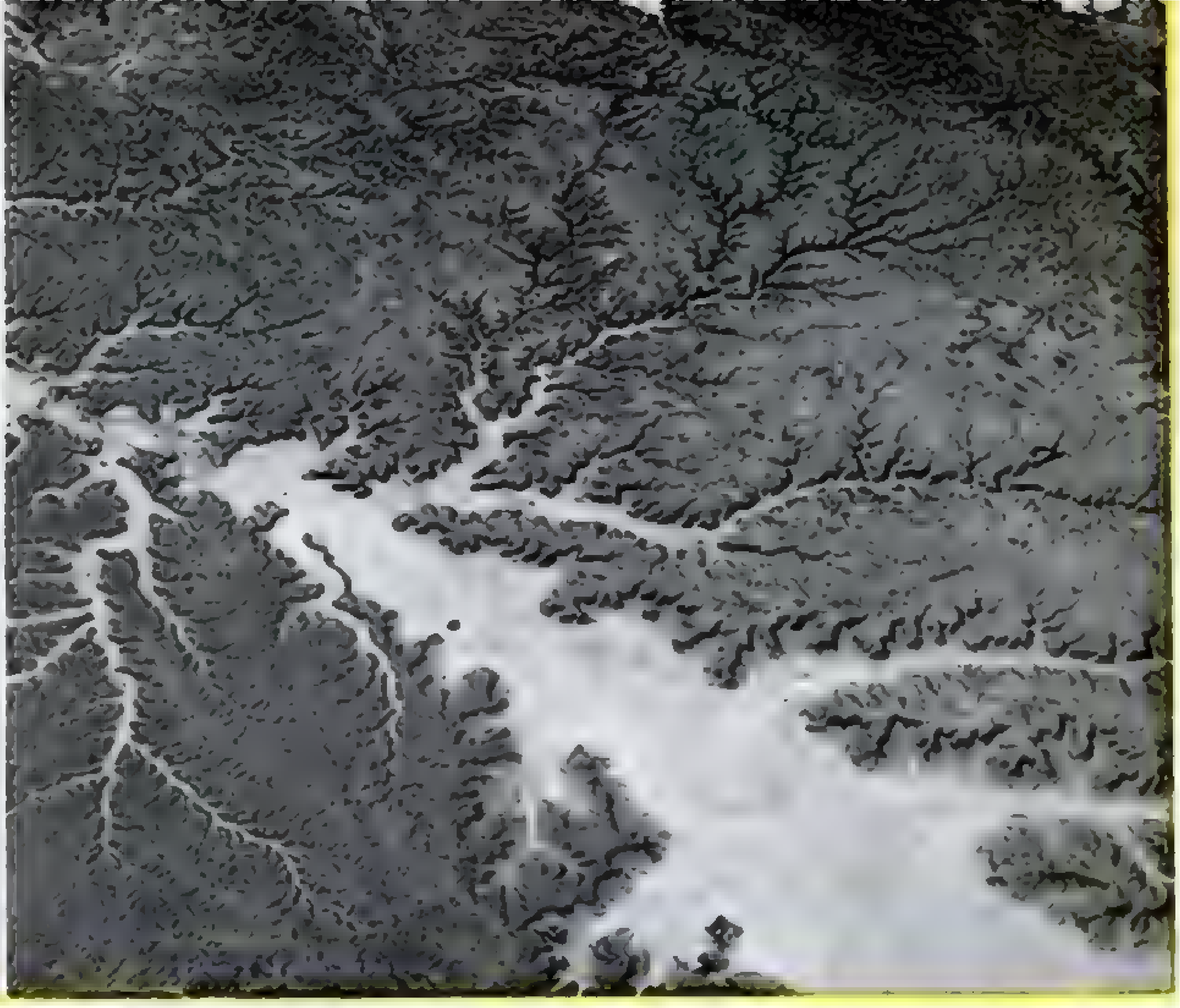
The hard and simple specification of an early manned landing on the moon has served to put our manned space program into high gear. And it has assured continuing public and Congressional support. For it would obviously be foolish to spend so much for manufacturing, testing, and launching facilities if we were not determined to invest further funds to man those facilities—and see the gigantic Apollo-Saturn program through to a successful conclusion. The moon landing, however, has never been this program's sole objective.

When Lindbergh soloed the Atlantic in 1927, he announced that Paris was his goal. But if his aim had been only to get to Paris, he might as well have taken a boat. The real purpose underlying his flight was to demonstrate, in terms everyone could understand, that the time had come to fly safely across the Atlantic Ocean. We all know what happened to aviation after that.

Today we believe the time has come for man to venture safely farther away from earth than our astronauts' voyages in low



Streets of El Paso, Tex., can be seen in view from more than 100 miles up.



Gemini photo bares topography of Arab plateau. These hand-camera shots could be excelled with space-observatory gear.

to the Moon

Dr. von Braun, right, plans this article with PS Editor-in-Chief Heyn after speech on same subject.

orbits so far. We think it is time to set foot on other heavenly bodies. The moon has become our cosmic Paris.

The payoff—as in Lindbergh's pioneering flight—will far exceed attainment of the immediate objective. Let us look into the four sorts of benefits I have named:

Aiding earth activities. First will come direct help for our earthly endeavors.

Unmanned satellites already give us a preview: Syncom and Early Bird satellites provide global television, radio, and telephone service. Tiros and Nimbus satellites and the new operational Tiros system are about to become vital elements of a worldwide weather-forecasting network. Transit satellites furnish a useful navigation aid for ships, and similar ones can be foreseen for air navigation and traffic control.

Manned satellites, including orbital space stations, will perform more and more of these tasks in the future—and new ones, too. Putting men in orbiting vehicles will prove a great advantage in weather-advisory systems, and for repair and maintenance of orbiting communications relays.

Man will play an even bigger role in orbital earth-observation posts to come:

Worldwide crop reporting from orbit can fill what will soon become an urgent need. Present trends of the population explosion indicate that the earth will have six to seven billion mouths to feed by the year 2000—and twice as many just 35 years later. The resulting problems of famines, strife, and struggle for sheer survival are not for the distant future to worry about, but for our own children and grandchildren. We must learn how to manage our planet's resources better—and must find out, first, how much food is available and where.

Sophisticated aerial photography, it has been demonstrated, can clearly identify various crops. You can tell a rye field from a barley or oat field, a farm growing soy

[*Continued on page 201*]

Bonanzas on the Way to the Moon

[*Continued from page 107*]

beans from one raising rice or corn. Moreover, you can distinguish a healthy crop from one affected by drought, or beset by stem rust or fungus. This method employs a series of films of different spectral sensitivity; and a battery of "remote sensors," simultaneously viewing the same spot on the earth's surface in different wavelengths of visible or infrared light. There is no reason to doubt that the technique, pioneered in airplane flights, could be used just as effectively from orbit.

Collecting crop data over the whole globe will need to be done continuously. Not only do plants change their appearance in growing; some weather-favored areas may be due for an exceptional yield, while other regions suffer from drought or floods. Only by keeping constant track of a given region will it be possible to come up with a realistic forecast for the current season's crop. To make such a continuous global survey with airplanes would run up an exorbitant fuel bill. To do it from orbit, year after year, really makes economic sense.

Once such a global survey exists, it can be used for other purposes as well. Systematic prospecting for oil and mineral deposits will become possible. A watch can be kept on volcanoes and other geologically unstable areas of the earth's surface, with an eye towards predicting eruptions or earthquakes. Systems can be provided to warn ships of icebergs, and thinly populated areas of forest fires. Observations of snowfall can give better forecasts for the water management of storage lakes, hydro plants, and irrigation systems.

Oceanography is another customer. Great possibilities await continuous global measurements of such phenomena as sea state, ice movements, water temperature, salinity (determined from orbit by polarimetry), and ocean-water coloration. (Green streaks indicate high plankton content and ability to support a greater fish population.)

National security. Since we have no plans ever to place nuclear bombardment missiles in orbit, Saturn-Apollo is unlikely to add to our national deterrent power. But, just as we can observe crops, storms, snow, and ice movements at sea, it stands to reason that we can also keep a watchful eye on things of military importance.

Undoubtedly, one of the greatest sources of danger in the world today is the Communist regions' secretiveness and their aversion to any kind of mutual-inspection scheme, because it often compels Western statesmen to depend upon educated guesses or assumptions rather than factual knowledge. Better information of what goes on, in their walled-off portions of the globe, will benefit our national security—and make this planet a safer place in the nuclear age.

Fundamental knowledge. Probably the most important truth man has learned, in the 10,000 years of his conscious history, is that it has paid him to satisfy his curiosity. The substance of what we call civilization —the house we live in, the clothes we wear, the ideas we pursue, the work we do, the car we drive, the books we read—can all be traced back to the simple fact that at some time someone was curious about something. Observing the universe from the vantage point of outer space—unobstructed by an atmosphere that blurs the stars' images and absorbs most of their radiation—is one of the best bets for man to enhance vastly his understanding of nature. It is up there that he may find the ultimate answer to what makes the universe tick.

Engineering and managing know-how. Putting a man on the moon and bringing him back alive not only calls into play a host of scientific and engineering talents; it requires a refined approach to what is called systems analysis—the art of predicting what a change in performance or defect, in one part or area, will do to other parts, other areas, and the whole system.

Entirely new management methods, too, have had to be developed. They enable the Apollo-Saturn managers to take prompt corrective action when something goes wrong in the complex machinery of an effort involving thousands of companies, hundreds of thousands of people, and hundreds of millions of dollars—and the entire, intimately interwoven program is in danger of falling out of step.

Many of these new managing techniques can be used to great advantage in fields as unrelated to space as high-speed interurban transit, and causes and remedies for air and water pollution. They can even be adapted to human relations problems, such as racial unrest and juvenile delinquency.

So, in blazing a trail to the moon, we are opening bypaths whose exploration promises rich rewards to come. PS

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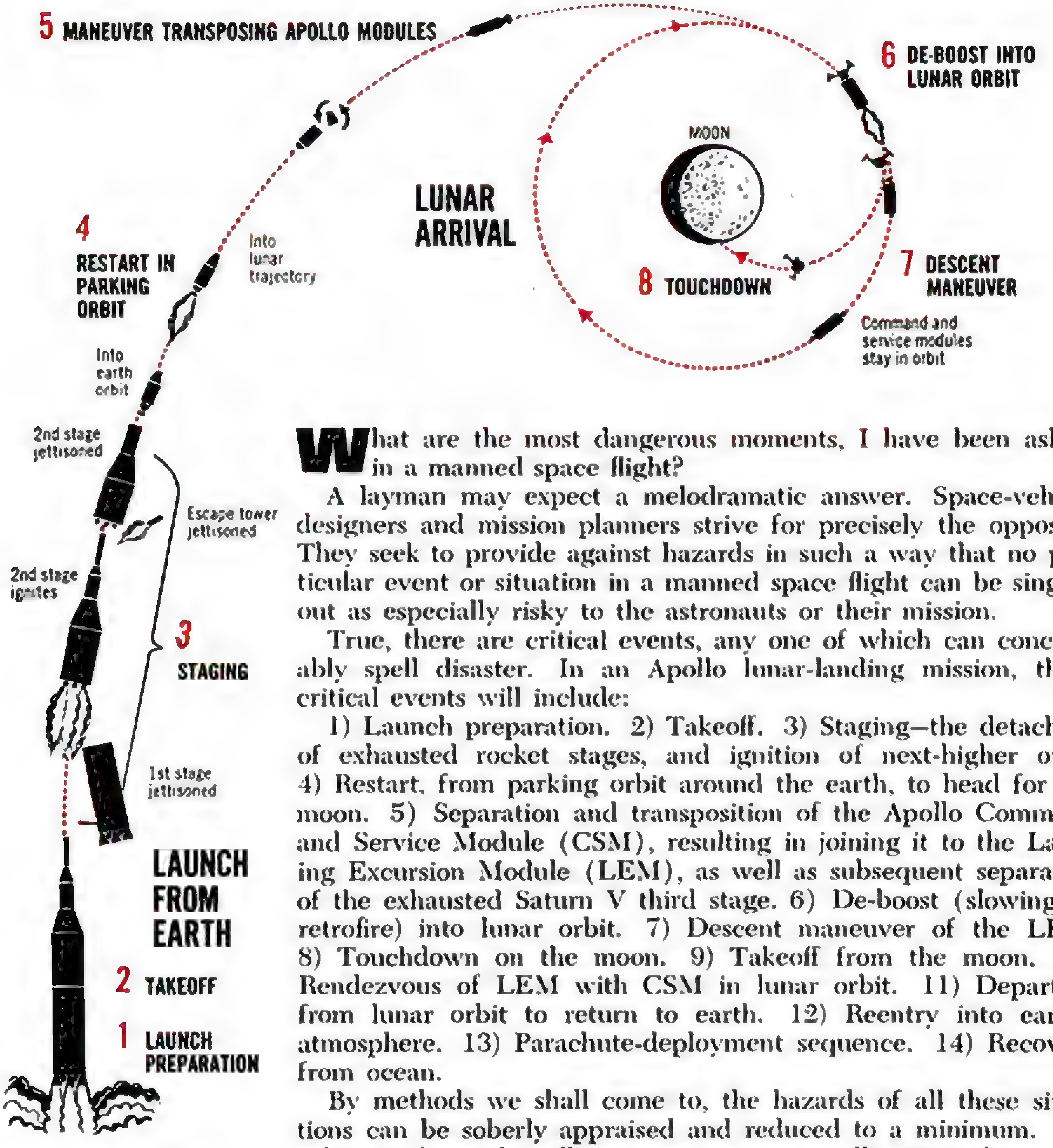
OME

Beating the Perils of Manned

To safeguard astronauts' lives and assure the success of their ventures, here are the ways space-vehicle designers and mission planners provide against dangers



Mission to moon conceivably could meet with disaster at any of these 14 critical points. Planners seek to make none riskier than rest.

What are the most dangerous moments, I have been asked, in a manned space flight?

A layman may expect a melodramatic answer. Space-vehicle designers and mission planners strive for precisely the opposite. They seek to provide against hazards in such a way that no particular event or situation in a manned space flight can be singled out as especially risky to the astronauts or their mission.

True, there are critical events, any one of which can conceivably spell disaster. In an Apollo lunar-landing mission, these critical events will include:

1) Launch preparation. 2) Takeoff. 3) Staging—the detaching of exhausted rocket stages, and ignition of next-higher ones. 4) Restart, from parking orbit around the earth, to head for the moon. 5) Separation and transposition of the Apollo Command and Service Module (CSM), resulting in joining it to the Landing Excursion Module (LEM), as well as subsequent separation of the exhausted Saturn V third stage. 6) De-boost (slowing by retrofire) into lunar orbit. 7) Descent maneuver of the LEM. 8) Touchdown on the moon. 9) Takeoff from the moon. 10) Rendezvous of LEM with CSM in lunar orbit. 11) Departure from lunar orbit to return to earth. 12) Reentry into earth's atmosphere. 13) Parachute-deployment sequence. 14) Recovery from ocean.

By methods we shall come to, the hazards of all these situations can be soberly appraised and reduced to a minimum. Resulting safeguards will aim to assure an Apollo mission's success from start to finish. And, even if the mission should fail, they are still to provide for bringing the astronauts back safely.

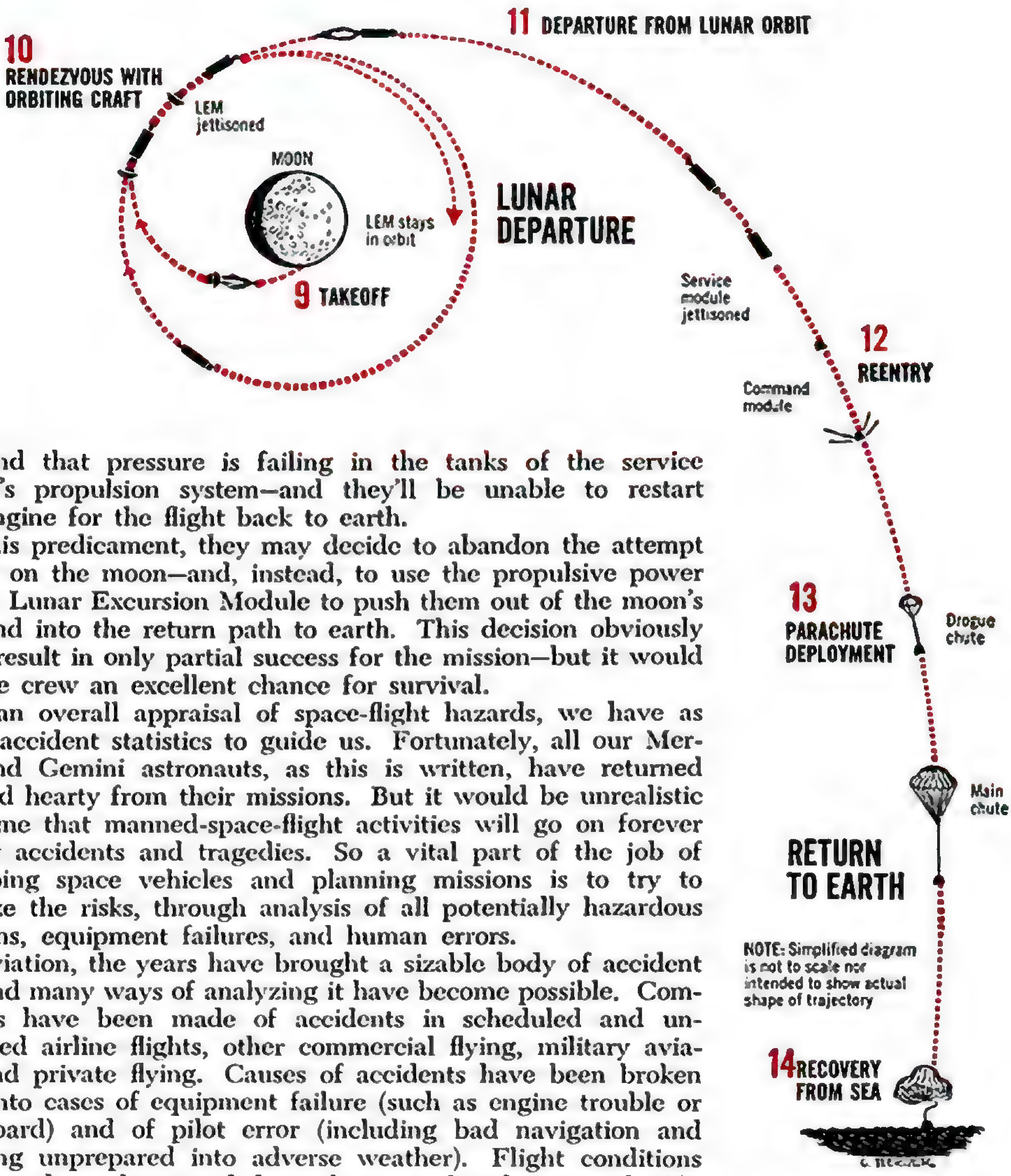
Getting out of a tight fix. Suppose, for example, that while an Apollo spacecraft's crew are orbiting the moon before landing,

Space Flight

By Dr. Wernher von Braun

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

On visit to PS, Dr. von Braun (holding papers) discusses his coming articles with Editor-in-Chief Ernest V. Heyn (far right), Executive Editor Hubert Luckett (between them), and Senior Editor Alden P. Armagnac (left).



they find that pressure is failing in the tanks of the service module's propulsion system—and they'll be unable to restart their engine for the flight back to earth.

In this predicament, they may decide to abandon the attempt to land on the moon—and, instead, to use the propulsive power of their Lunar Excursion Module to push them out of the moon's orbit and into the return path to earth. This decision obviously would result in only partial success for the mission—but it would give the crew an excellent chance for survival.

For an overall appraisal of space-flight hazards, we have as yet no accident statistics to guide us. Fortunately, all our Mercury and Gemini astronauts, as this is written, have returned hale and hearty from their missions. But it would be unrealistic to assume that manned-space-flight activities will go on forever without accidents and tragedies. So a vital part of the job of developing space vehicles and planning missions is to try to minimize the risks, through analysis of all potentially hazardous situations, equipment failures, and human errors.

In aviation, the years have brought a sizable body of accident data, and many ways of analyzing it have become possible. Comparisons have been made of accidents in scheduled and unscheduled airline flights, other commercial flying, military aviation, and private flying. Causes of accidents have been broken down into cases of equipment failure (such as engine trouble or fire aboard) and of pilot error (including bad navigation and venturing unprepared into adverse weather). Flight conditions when accidents happened have been analyzed, too: takeoffs, landings, and flying under conditions of high or low visibility, smooth or turbulent air, icing, thunderstorms, and so on.

For space hazards, a new method. Without such data for space,

Continued

how can we get a good handle on space-flight hazards? Considerable progress has been made. Far from being a mere paper study, lacking practical significance for want of experience to go on, is the new art of "reliability analysis." It provides most valuable hints to the space-vehicle designer as to where he should make an extra effort to reduce a potential hazard.

The basic approach to a reliability analysis is quite simple. Usually one begins with an arbitrarily chosen "reliability target" for the whole flight mission. Suppose this is an Apollo-Saturn flight to the moon and back, including a lunar landing. Let us assume—and my figure is for illustration only—that a reliability target of 90 percent is set for the entire mission, including safe return to earth. That would mean that nine tries out of 10 must succeed.

We now parcel out this overall reliability target to the three propulsion stages and the one guidance stage of the Saturn V launch vehicle, and to the three modules of the Apollo spacecraft riding in the Saturn V's nose. Suppose—again, solely for illustration—we allot a reliability requirement of 99 percent to *each* of these seven elements of the whole space vehicle.

According to the laws of probability, the overall reliability of the entire space vehicle will then be the product obtained by multiplying together seven .99s, which is .93 or 93 percent. This betters our overall 90-percent target by three percent, which we may allot to hazards unrelated to equipment, such as successful touchdown on the moon and rendezvous in lunar orbit.

Now we can go on to the next step and see if the booster stages and spacecraft modules really offer the 99-percent reliability demanded of them. This calls for "qualification-testing" all critical components of a stage or module, under environmental conditions more severe than the actual flight environment of a space vehicle, before they are admitted to the assembly. The tests are applied, not to parts of any actual space vehicle, but to similar pieces from the same manufacturing line.

Often this procedure shows that certain parts of a stage simply cannot be made reliable enough to pass the severe tests. Invariably the answer is redundancy—provision of a back-up component that can take over the job if the other one fails.

Redundant components are nothing new in engineering. Your car has two headlights, in case one goes out. Large aircraft have two or more engines, and several independent radios. In manned space flight, with its unprecedented demands for near-perfection, providing redundancy has become a highly sophisticated art.

Wherever advisable and possible, Project Apollo-Saturn provides redundancy not only in components, but also in alternate choices of operational procedures. Thus, midcourse navigation between earth and moon can be performed by astronomical navigation aboard the spacecraft, as well as by radio and radar tracking from the ground. Life support can be provided either by the crew compartment's pressurizing system or, if that fails, by the astronauts' space suits.

Usually the reliability-allotment game is played through several times before the figures are finally cast in concrete. The higher the target is set, the greater will be the weight and complexity of the system, until handicaps offset further gains.

Dual stakes—lives, mission. Reliability requirements for crew survival and mission success are by no means identical. For instance, if the launch vehicle develops serious trouble during boosted ascent, the mission will be lost anyhow. But we are still faced with enabling the crew to abort safely and return to the earth's surface. The reliability to be expected of various conceivable abort modes, during a space-flight mission, can be quite different.

After all humanly possible precautions are taken, whatever hazards remain in a manned space flight result from the overall complexity of manned space missions and the vehicles needed to fly them. When all is said and done, we still have to live with the fact that every time a space vehicle takes off, there are hundreds of thousands of not-so-perfect human beings involved in the act.

Since the dawn of the Space Age, many people active in our national space program have been involved in travel and household accidents. Even some of our astronauts have not been spared. So, in appraising the overall risk of flying to the moon, we should not completely disregard the hazard of the astronauts' travels to their training stations and their final automobile ride to the launch pad. PS

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For Astronauts in Trouble...

Here's what the crew of a spacecraft do, in case they should face an emergency on their way to orbit

By Dr. Wernher von Braun

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

Dr. von Braun, right, talks with Capt. Walter Schirra, who vetoed Gemini 6 abort—and later flew craft to rendezvous with Gemini 7.

When trouble strikes a manned spacecraft in the "launch phase" between earth and orbit, the urgent thing is to get the astronauts safely back to the ground. Several ways to do it have been developed in the course of our space program. They have notable differences, both in the mechanics of the escape method and in how it is triggered into action—as is illustrated by the evolution of escape procedures in our successive Mercury, Gemini, and Apollo projects.

During launch preparation and the first 50 or 60 seconds of a manned space flight, the use of ejection seats like those of military aircraft is still possible. The Gemini spacecraft actually provides this means of escape.

At higher speeds, however, ejection into the slipstream becomes out of the question. And at near-orbital velocities, although the force of the onrushing air subsides as the launch vehicle climbs above the atmosphere, reentry heating poses another insurmountable obstacle for unprotected bailout.

For these reasons, astronaut emergency procedures during the launch phase are based upon the ground rule: Stay in your spacecraft, come what may, and ride down with the ship! Escape from a Gemini launch by ejection

Continued

Low-altitude escape systems of U.S. manned spacecraft are compared pictorially

Mercury, Gemini, and Apollo escape systems illustrate evolution of methods. Mercury capsule is automatically yanked out of danger by escape rocket, linked to it by tower—and then, jettisoning tower, descends on parachute, with the astronaut inside. Gemini astronauts, at altitudes from zero to 15,000 feet, use manual-controlled ejection seats to abandon capsule, and swing down on individual chutes; higher up, they stay with capsule and bring it down on its own chute. New Apollo system reverts to use of escape rocket to hurl whole capsule away from disabled booster—but reserves automatic triggering for fast-developing emergencies, and adopts manual control by astronauts for use in other emergencies.

This Way Out

Successful trial shows how Apollo escape rocket would hurl the manned capsule out of danger.

seats during the first minute is the only departure from this rule.

Escape rockets for capsules. The one-man Mercury capsule and our new three-man Apollo craft have no ejection seats at all. In case of serious booster difficulties during the ascent through the atmosphere, a powerful short-burning solid-propellant rocket jerks the capsule away from the trouble-stricken booster—and to a safe distance, lest the booster explode. Parachutes then ease the spacecraft, with the astronauts inside, all the way to the ground.

Gemini astronauts, too, stay in their spacecraft in case of an emergency after the first minute of flight. Firing its own retro-rockets in salvo (or, later, its thrusters), the two-man capsule separates from the shut-down booster and a parachute lowers it to earth.

The triggering problem. When a multi-stage launch vehicle takes off from its launch pad, and shoves the manned spacecraft in its nose into orbit within a few minutes, large numbers of highly complex systems are activated, turned off, and detached in rapid sequence. Whenever trouble hits during the launch phase, it is liable to hit fast. In certain cases it may even hit so fast that there might not be time for the astronauts to consult their display panels and make a decision.

Automatic abort has seemed the only answer in such cases. Yet it is not very popular with astronauts. This should not be too surprising. After all, how would you like to ride an airliner in an ejection seat that could be triggered automatically—any time a little black box, somewhere in the plane, decided it was best for you to get out of the aircraft in a hurry? There is no perfect answer to the two very serious sides of the argument.

The Mercury program did use an entirely automatic crew-safety system. Symptoms of impending launch-vehicle failure were sensed and wired to trigger automatic abort. The booster engines would be cut off, the spacecraft would separate, and the escape rocket would be fired to hurl it safely clear. This in turn would trigger subsequent events, such as the jettisoning of the escape tower, and parachute deployment.

The Gemini crew-safety system, in contrast, is entirely manual. The various indications of potential launch-vehicle failure are displayed to the flight crew. But it is the crew's decision whether or not to initiate abort action. On at least one occasion, a Gemini command pilot did actually decide against heeding the abort advice flashed on his display panel:

A warning overruled. During an attempt to launch Gemini 6 last December 12, the two engines of the Titan booster's first stage shut down without lifting the vehicle off the pad. Due to the engine vibrations, an electrical plug had prematurely dropped out of the still-tied-down booster.

This plug disconnection—since it normally would have occurred only through the movement of the rocket after actual lift-off—started the on-board timer and the guidance and control system, and made the on-board electrical logic system "believe" that the bird was in flight. A few seconds later a timer in the ground-support equipment, not having received a tailgrab-release signal within a specified period of time, shut down the booster engines. The crew-safety system went on to conclude, quite logically, that a dire emergency demanding immediate abort had arisen—apparently the "rocketborne" vehicle, its engines failing, was about to fall back on its pad.

In effect this advised the two astronauts to pull D-shaped rings actuating their ejection seats. Hurtling about 300 feet high and 800 feet sideward, they would then swing to earth on their parachutes.

But the command pilot, Capt. Walter Schirra, was sure the bird had never left the pad. He disregarded the warning signal. His correct split-second decision attested to his presence of mind—and to the fact that there is indeed much merit in giving man a role in the decision-making.

Apollo's crew-safety system. In the Apollo-Saturn program, an approach halfway between Mercury and Gemini has been taken. Vehicle-failure situations that can be expected to lead only slowly to catastrophic conditions are indicated on a display panel, and the decision to execute abort is left to the flight crew. Failure situations that are bound to lead rapidly to disaster will trigger automatic abort.

Whether automatic or manual, crew-safety systems must be as simple as possible. Simplicity enhances assurance that the system will really work—and also reduces the hazard of a false alarm that could unneces-

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For Astronauts . . . This Way Out

[*Continued from page 74*]

sarily abort a perfect flight. The most effective way to simplify the system is to make it sense the result of a malfunction, rather than the malfunction itself.

One of the most critical situations arises if one of a space rocket's swivel-mounted engines should suddenly go "hard over," or tilt to an extreme angle. For steering, rocket engines are deflected back and forth a few degrees by hydraulic pistons ("actuators"), according to signals received from the control computer. A "hard over" could conceivably result from either an electrical or a hydraulic failure.

By sensing the movements of eight actuators, one could provide "hard-over" warning indicators, but this would be a rather complex installation.

Instead, we might disregard the actuators and simply sense the whole vehicle's turning rate and angle of attack. What concerns us is not an engine's deflection, but the result—the vehicle's rapid turn, and the build-up of an excessive angle of attack that might cause its structural breakup.

Considerations like these have led to the following crew-safety system for the Saturn V/Apollo moon-rocket vehicle:

- Automatic abort will be triggered if two or more rocket engines of the Saturn V shut down after lift-off; or if the vehicle builds up a rotation rate, in the pitch or yaw plane, of faster than five degrees per second; or if the vehicle starts rolling faster than 20 degrees per second.
- Manual abort is executed at the command pilot's discretion. He has at his disposal the following cues: angle-of-attack display, in pitch and yaw planes; turning rates in pitch, yaw, and roll, as indicated by the spacecraft's own guidance system; and an abort request radioed up by the flight director, who takes his cues mainly from telemetered data.

Escape from orbit. In case of trouble after a manned spacecraft is in orbit, the only conceivable way out—short of future orbital rescue efforts by other spacecraft—is to fire the retrorocket system and reenter the atmosphere. If possible, the astronauts will defer their retrorocket maneuver until the resulting reentry path will end near a recovery ship. Even if a medical emergency should befall a crew member, the 18,000-m.p.h. capsule will always be the fastest ambulance available.

Popular Science

AMAZING CONE DRIVE: IT'S A TRANSMISSION, CLUTCH, DIFFERENTIAL —ALL IN ONE

THE FABULOUS

that recovered B

WE NEED YOUR INVENTIVE SKILL! By Vice President Hubert H. Humphrey

ling? ...How Airflow Affects Your Driving

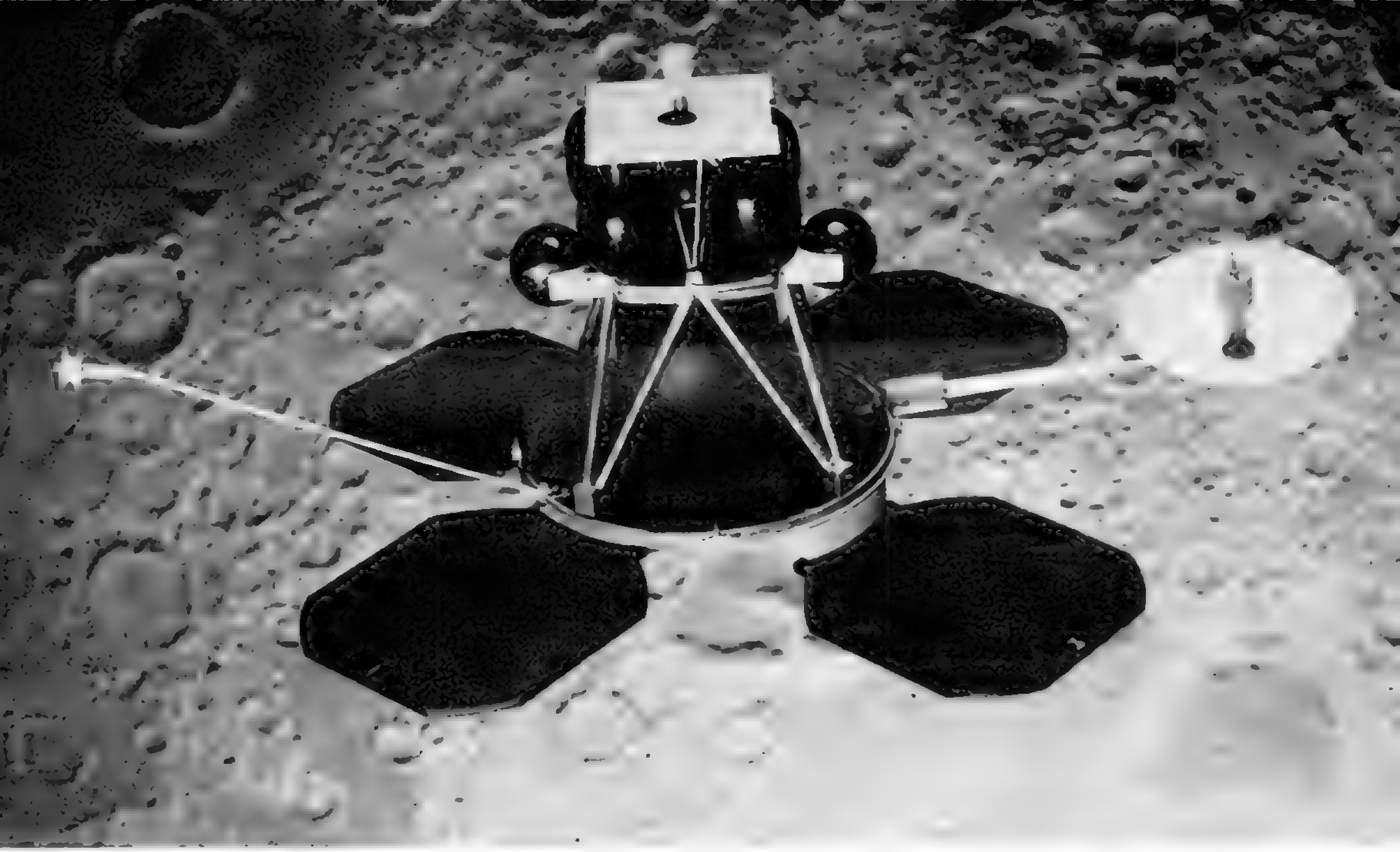


Photo Spacecraft to Circle

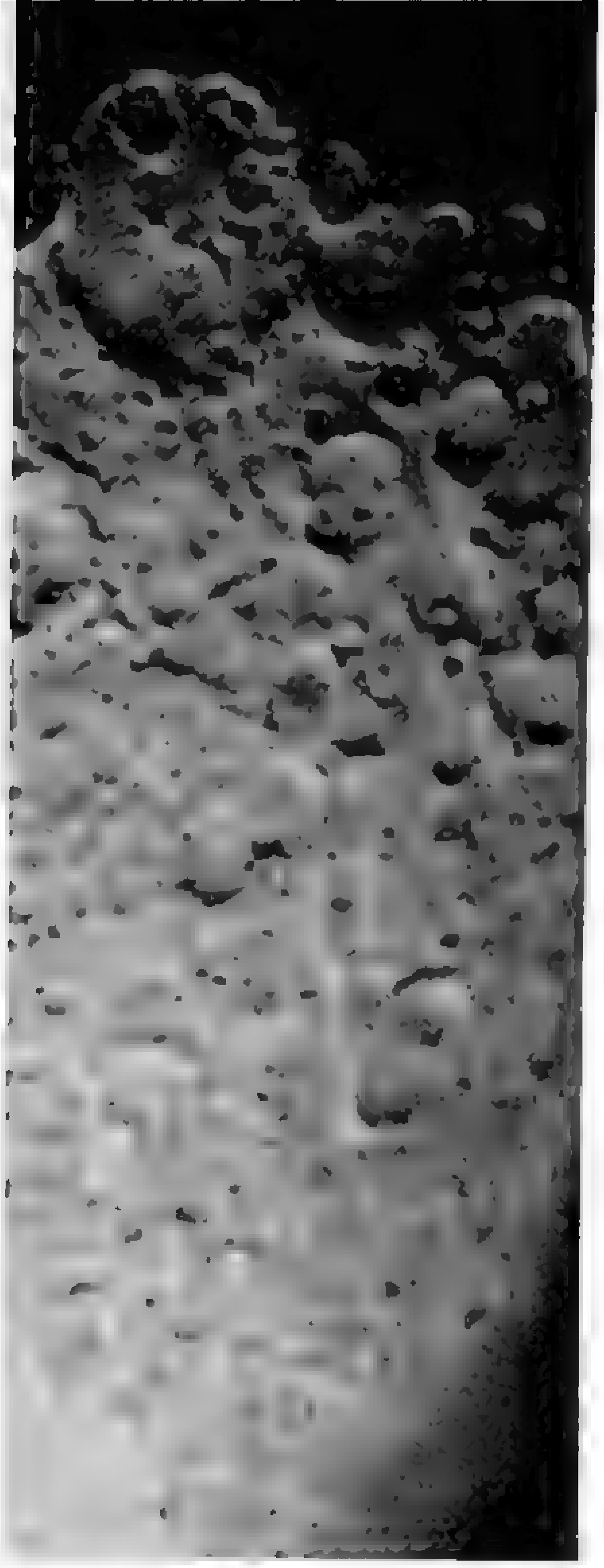
From 28 miles away, our Lunar Orbiters' cameras will scan the surface of the satellite to pick out favorable landing sites for our Apollo astronauts

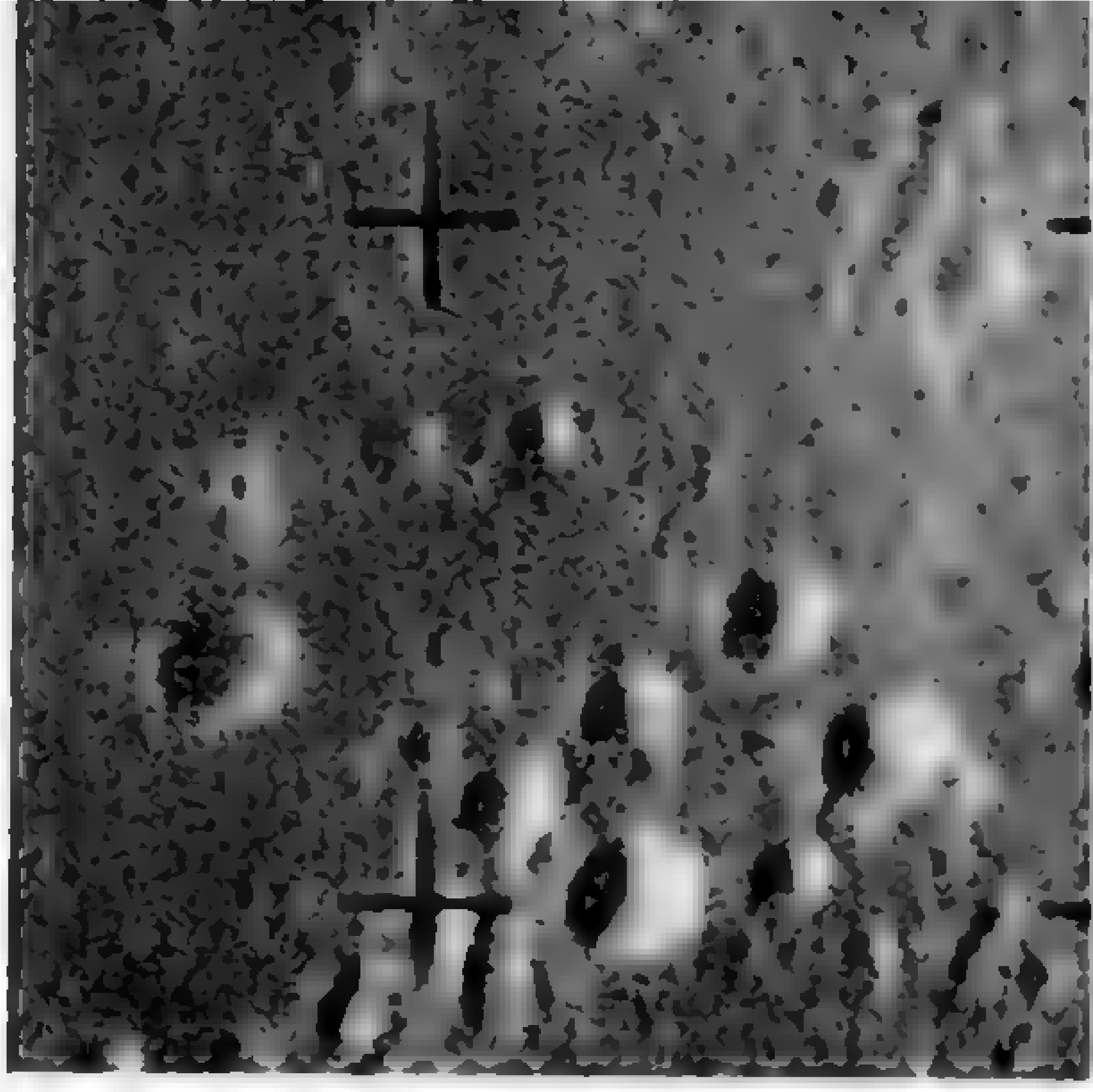
By DR. WERNHER VON BRAUN
Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

This summer, the first of a series of five Lunar Orbiter camera spacecraft will be launched. Circling the moon, they will photograph extended belts of lunar terrain from surface-skimming orbits only 28 miles high at nearest approach.

Taking pictures of potential landing sites on the moon for our Apollo astronauts will be the main purpose of these unmanned, 850-pound U.S. space vehicles. A secondary objective is to photograph larger areas of particular interest—on the moon's far side, or in its polar regions—to gather a wealth of topographical and geological data.

What a Lunar Orbiter will look like may be seen from the model illustrated above. A pumpkin-shaped container at the center houses the photographic equipment. Four black "paddles" are solar panels that generate 266 watts of electric power. The white arms extending from the sides are antennas—a dish-shaped directional one to bundle signals to earth after the spacecraft is properly oriented, and a fishing-reel-shaped antenna for continued radio contact between the craft and the earth during loss

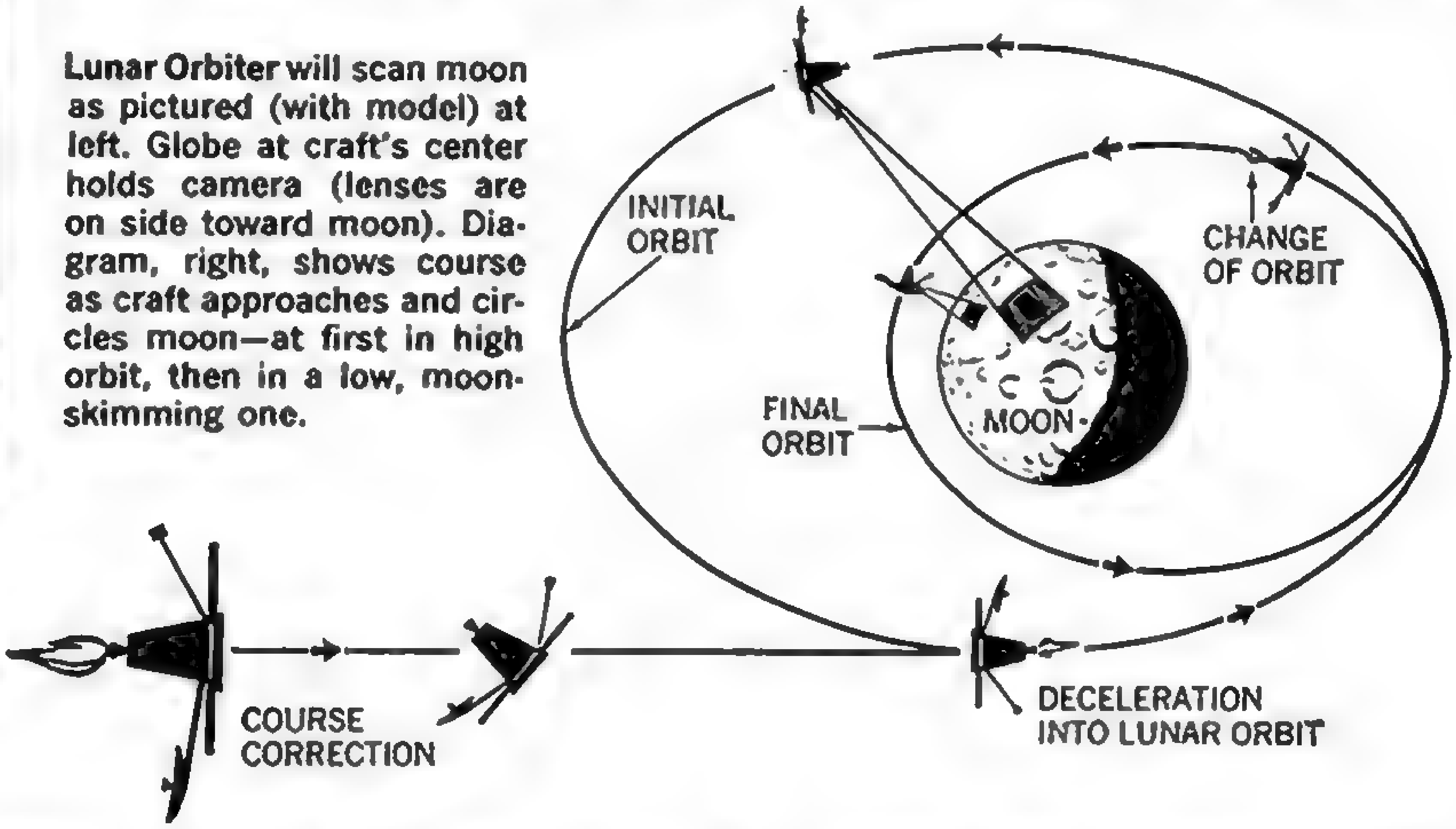




Closest photos by Lunar Orbiter will be much sharper than this Ranger view—which, likewise, covers 20 square miles.

Moon-surface photo was made by USSR's soft-landed Luna 9—which itself should be spotted if a Lunar Orbiter scans site.

Lunar Orbiter will scan moon as pictured (with model) at left. Globe at craft's center holds camera (lenses are on side toward moon). Diagram, right, shows course as craft approaches and circles moon—at first in high orbit, then in a low, moon-skimming one.



Moon

or temporary alteration of this attitude.

The nozzle atop the spacecraft model, protruding from a white heat shield, is part of the 100-pound-thrust rocket-propulsion system that enables the spacecraft to correct its course and to make changes in its lunar orbit.

An innovation: photos from orbit. Up to this writing, the moon has been photographed by spacecraft maneuvered in three different ways: in a curving trajectory past the moon (Russia's Luna 3 and Zond 3), to a crash landing on the moon (our Rangers 7-9), and to a soft lunar landing (Russia's Luna 9). Photos from a moon-orbiting spacecraft will be something new. Though not as close up as views from impacting or soft-landing spacecraft, they will have the advantage of covering far more lunar territory, at a range still near enough to disclose quite small details.

A Lunar Orbiter's single camera will take pictures alternately with a telephoto lens and a comparatively wide-angle lens. A

[*Continued on page 200*]

Moon photographs by spacecraft

To date:

1959	USSR	Luna 3	Far side, from about 40,000 miles
1964	USA	Ranger 7	Near side, up to impact (nearest: 1,000 feet)
1965	USSR	Zond 3	Far side, from about 7,000 miles
1965	USA	Ranger 8	Near side, up to impact
1965	USA	Ranger 9	Near side, up to impact
1966	USSR	Luna 9	Near side, on surface (after soft landing)

(USSR's Luna 10, put in lunar orbit April, 1966, did not carry any photographic equipment)

Coming, 1966-67, U.S.:

Lunar Orbiter 1 to 5	Near and far sides, from about 28 miles
Surveyor 1 to 10	Near side, on surface (after soft landing)

[Continued from page 93]

frame made with the telephoto lens will be able to register a 20-square-mile area so sharply that it will be possible to distinguish an object as small as a card table. The wide-angle lens will photograph about 350 square miles with high enough resolution to reveal a feature of the lunar surface no larger than a boxing ring.

Successive wide-angle frames will overlap. A pair of the frames, like adjacent aerial photos of the earth, can be placed in a stereo viewer and seen in three dimensions—extremely helpful in relief, or contour, mapping. The ability to do this is another of the advantages of photographs from lunar orbit.

The film in a Lunar Orbiter's camera will be a long, 70-millimeter-wide strip. After exposure it will pass through a processor in which it will be developed and dried, yielding a high-quality film negative.

To transmit the pictures to earth, the TV-like technique will be basically the same as the one successfully used in our Ranger spacecraft. A moving light beam will scan the negative and fall upon a photomultiplier, which converts variations in lightness and darkness into corresponding fluctuations of electric current. This "electrical equivalent" is radioed to earth, where the process is reversed and a photographic image is reconstructed. The Lunar Orbiter photos are expected to excel the Ranger views by far in quality of resolution, with the help of the much more powerful optical system to be used.

Lunar Orbiter's flight plan. A typical flight will follow this program: An Atlas/Agena launch vehicle hurls the Lunar Orbiter from its pad at Cape Kennedy, Fla. The Agena, during its first burn after separating from the Atlas booster, puts the spacecraft into a parking orbit about 100 miles above the earth.

Then, at an instant determined by the moon's own orbital motion around the earth, the Agena restarts for its second burn. It pushes the spacecraft out of the parking orbit and into a moon-bound course. On reaching a speed of about seven miles per second, the Agena shuts down, and the spacecraft separates from it—for a three-day unpowered coast to the moon.

During the journey, as well as afterward, nitrogen-gas jets control the attitude of the spacecraft so as to keep the directional antenna aimed toward the earth, and the solar panels toward the sun. For this purpose, the jets are activated by a pair of sensors. A "sun sensor" keeps itself, and the lengthwise axis of the spacecraft, trained on the sun—the brightest object in the sky. Meanwhile a "Canopus star tracker," looking sideward, locks itself upon the brilliant star Canopus—thus checking rolling, and completing the steadying of the craft in space.

When either the sun or Canopus is not visible, a gyroscopic "inertial reference unit" takes over attitude control of the spacecraft. During short passages through the shadow of the earth or moon, when the solar panels are inoperative, nickel-cadmium batteries provide electricity.

After a last correction of the spacecraft's course as it nears the moon, it brakes itself with its own rocket. This enables the tug of the moon's gravity to whirl it into a lunar orbit—initially, at a high altitude. (For awhile its course will be closely watched for "wobbling," due to any irregularities or departures from symmetry in the moon's gravitational pull, to make sure it can safely be brought as near the surface as intended.) Then, by firing its rocket once more, the spacecraft changes its orbit to a low one that provides the best photographs.

Other data, too. After exposing all their film, the Lunar Orbiters are to transmit information for several months on the abundance of micrometeoroids and the level of radiation encountered in orbit around the moon. Gradual changes in the unpowered orbits will give scientists greatly improved data, also, on the moon's gravitational field and the lunar tidal effects produced by the earth's gravity. All this information is of vital interest to our forthcoming manned Apollo-Saturn flights to the moon.

Systems management of the Lunar Orbiter program is handled by NASA's Langley Research Center. The program's overall direction, on the Washington level, rests with NASA's Office of Space Science and Applications. Prime contractor is the Boeing Company, with Eastman Kodak and RCA the respective subcontractors for photographic and electronic subsystems. Evaluation of results is being coordinated by NASA-Langley, Jet Propulsion Lab, NASA-Houston, U.S. Geological Survey, Air Force Aeronautical Chart and Information Center, and the Army Map Service. PS

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Popular Science

MONTHLY

Last-Minute News! What the '67 cars will really be like

All in This Issue:

BUILD YOUR OWN TREASURE FINDER

THE "HEART CART" MAY SAVE YOUR LIFE

INSIDE STORY OF BATMAN'S BATMOBILE

THE TRUTH ABOUT WHEEL BALANCING

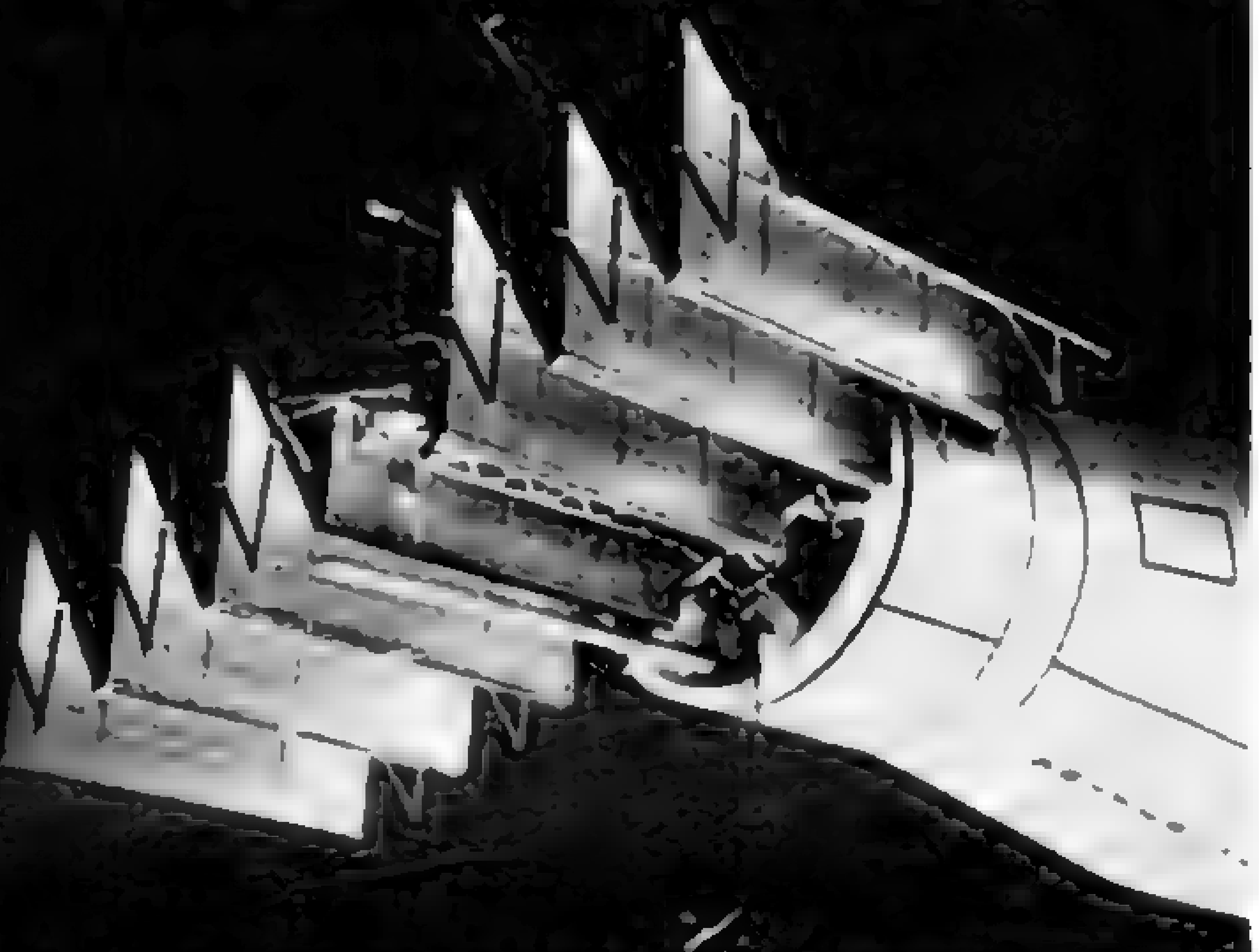
Amazing Glass-Bubble → Underwater Pleasure Craft

"WHAT I LEARNED IN FAST-DRIVING SCHOOL"

What three giant unmanned satellites have told us about the hazards of micrometeoroids — the dust-size particles flying faster than bullets through space

THESE SPACECRAFT

Pegasus satellite arrives in orbit with its giant wings still folded, as above.



Hinged wings of Pegasus begin unfolding, to expose meteoroid-counting panels.

By DR. WERNHER VON BRAUN

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

Three giant Pegasus satellites, all launched during 1965 and still working at this writing, are closing a gap in our knowledge about the hazards of meteoroids to our astronauts and their spacecraft.

The Pegasus satellites are reporting the first observations ever made, at close hand, of the abundance of meteoric particles that can penetrate metal as thick as 1/60 of an inch. Because these particles are infrequent, compared to smaller and less-penetrating ones, a meaningful count in a reasonable time takes a huge collecting area. Hence a Pegasus has a wing-like meteoroid-detecting surface of 96-foot span.

What we call "meteoroids" are pieces of matter hurtling through space, regardless of size. They become "meteors" if they enter our atmosphere, "meteorites" if they reach the ground unconsumed. Meteoroids come in sizes from a dust speck ("micrometeoroids") to a city block and more. The biggest are few and far between. Specks too tiny to puncture a space vehicle's skin hit a Gemini-size craft many times a day. It is the stuff of intermediate size that concerns a space-vehicle designer.

Dr. von Braun (second from left) attends a NASA-Fairchild-Hiller conference on Pegasus project at Hagerstown, Md., plant of satellites' maker.

Dangers from meteoroids. Particles of only a few thousandths of a gram, whizzing at 15 to 20 miles a second, can penetrate a spacecraft's wall or a rocket's tank. They constitute a definite risk. If they puncture a tank or gas compartment, the result can be a serious leak—or, possibly, explosive rupture of a tank under pressure. Heat from their impact may ignite certain propellants, or materials in a crew compart-

SAY "OUCH!"

With wings extended to full 96-foot span, Pegasus is ready for its space mission of reporting impacts by meteoroids.

ment's oxygen-enriched atmosphere. And meteoroid-caused "spalling"—ejection of flying fragments of a spacecraft's interior wall surface—can form secondary projectiles endangering the crew and vital parts of their craft's equipment. Determined and costly efforts have therefore been made by NASA to appraise the meteoroid hazard.

Before the Space Age, optical observation of shooting stars had yielded considerable data on the abundance of meteoroids, and radar observation later added more. But these methods detected meteoroids no smaller than about a thousandth of a gram.

Close-range studies. Beginning with Explorer I, the first U.S. satellite, space probes were equipped with microphonic and electrical devices to record the impact of meteoric dust. Particles as small as a million-millionth (1/1,000,000,000,000) of a gram were detectable. But the collecting devices offered a target area of only a few square inches—rarely hit by meteoroids big enough to interest space-vehicle designers.

The Pegasus project's aim was to fill the void of data on meteoroids weighing between about a thousandth and a 10-millionth of a gram. For launching the big 33,000-pound Pegasus satellites, the Saturn I rocket proved well suited. NASA's Marshall Space Flight Center, responsible for developing Saturn I, was also placed in charge of developing the Pegasus spacecraft.

A target as big as a house. The wings of a Pegasus, which unfold in orbit, are covered on both sides with aluminum plates that serve as targets for meteoroids. This provides a total collecting surface of more than 2,000 square feet—the floor area of a large one-family house. Most of the aluminum plates are 1/60 of an inch thick. Others have a thickness of 1/120 of an inch; a few, of 1/600 of an inch. This enables a Pegasus to register meteoroids of three different degrees of penetrating power.

Pegasus has an electronic system whose main function is to say "ouch" every time a hit occurs—and say it in such a way that the signal received on the ground can be intelligently interpreted. Beneath each aluminum plate is a film of plastic, coated on the other side with copper. This aluminum-plastic-copper sandwich, forming an electric capacitor, is charged to 40 volts.

Each time a meteoroid punctures the aluminum, material vaporized by the impact momentarily short-circuits the ca-

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These Spacecraft Say "Ouch!"

[*Continued from page 77*]

pacitor—and a memory system records the event. On ground command, Pegasus reads out all data. This gives a count of the meteoroids that have pierced a known area of each thickness in a known time.

Since the Pegasus satellites are still collecting data, their findings are not yet complete. However, a chart made public by NASA summarizes what they have told us in their first 10 months of operation.

What the satellites say. According to this preliminary summary, the yearly meteoroid punctures in a square foot of aluminum sheet, on the outside of a spacecraft in low orbit, can be expected to number somewhere near:

- 7, for 1/600-inch sheet.
- 0.6, for 1/120-inch sheet.
- 0.13, for 1/60-inch sheet.

Now, an intact 10-foot sphere, which has a surface area of 314 square feet, could safely withstand an internal pressure of one atmosphere and provide an earthlike environment for astronauts in outer space, if made of 1/60-inch aluminum. But the Pegasus findings indicate that it would be punctured about 40 times a year. So that wall thickness, for a manned spacecraft, would expose a crew to serious meteoroid hazard during extended space flights.

Fortunately, spacecraft capable of reentry into the atmosphere—like Mercury, Gemini, and Apollo—have a healthy padding of heat protection that greatly reduces the penetration hazard. But space vehicles and space stations without reentry capability are under development for extended operating times in space. So adequate meteoroid protection is becoming more important than ever. With better meteoroid data, designers will be able to provide enough "armor" to reduce the risk from meteoroids, in any given space mission, to a figure commensurate with other risks that must be accepted.

The gap in our knowledge is not yet completely closed. We'd like to know the abundance of meteoroids that can penetrate aluminum sheets as thick as 1/25 and 1/10 of an inch, figures representative of many space-vehicle structures. NASA has announced that it plans to tackle the problem of that remaining gap during the coming year. Satellites still larger than Pegasus, or a greater number of Pegasus-size satellites in orbit at once, could be possible ways. PS

AUGUST 1966 35 CENTS

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MONTHLY

What's Best for You–Disk or Drum Brakes?

JAN NORBYE debates SMOKEY YUNICK

How They Do Th ... cks

• Save Your Car from Rust an ... Wiring

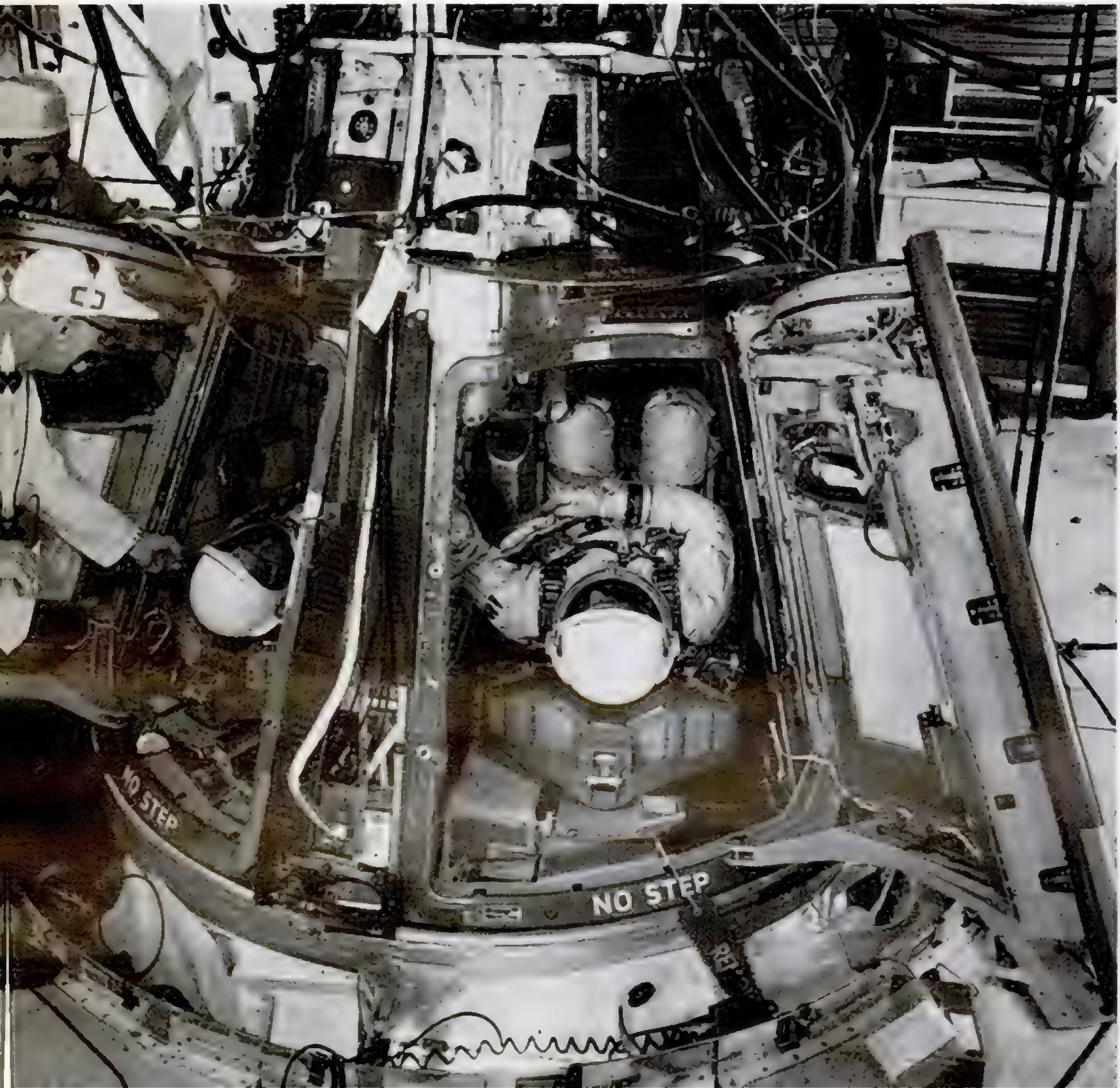
• Cold War in Space by WILLY ... Color

Now it's time to put A Living Room

We're ready to cross the "comfort barrier" in space—and give our astronauts more homelike quarters for those long missions coming soon

By DR. WERNHER VON BRAUN
Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

Year-long missions demand more comfortable quarters than Gemini's cramped room, below.



Huge hydrogen tank of Saturn IB's spent second stage could become "living room" in space. Drawing shows proposed trial by an Apollo crew.

in Orbit

"Inject water, knead, and squeeze the broth through your teeth." Day after day of such Spartan fare for food, and of all the other hardships of their Gemini 7's cramped quarters, tested the fortitude of Frank Borman and Jim Lovell in their record two-week space flight last December.

Pioneering has always been uncomfortable. No band of men could ever have been more willing to accept its discomforts than our astronauts. But coming missions will demand making manned spacecraft more livable.

Our manned-space-flight program is entering its second major phase. Now that we have demonstrated that man can live and work in space for a long time, we must put him to practical use. And future manned space missions should be the more useful, the longer man stays out there.

The "why" of long missions. For a long time to come, space flights will be expensive. The costliest single item, until we have re-usable launch vehicles, will be the rocket booster. Thus, the more useful time we can get out of a single launch, the less will be the cost per man-hour in space.

A miles-to-the-gallon approach favors long missions, too. Each manned launch into orbit costs many thousands of gallons of fuel. But once the crew is up there, no more fuel is needed to keep them there. With each circuit in low orbit they travel about 27,000 miles. Thus, if a manned spacecraft stays up for enough orbits, its economy can put a Volkswagen to shame.

Long stay-times in orbit will therefore be the rule, rather than the exception, for useful manned missions near the earth. For a man to work long and most proficiently in space, we must provide him with a reasonable degree of comfort—whether he serves as a pilot, scientist, repairman, operator of commercial equipment, or military observer. And this is just as important for future astronauts setting out for the planet Mars, a voyage that may last well over a year.

What's called for. The basic ingredients of comfort in space flight are not too different from our ideas of comfort on earth:

- Temperature. When there is not much physical activity, 72 degrees F. is considered ideal. Variations should not exceed five degrees warmer or cooler. Environmental-control systems of spacecraft can easily maintain the temperature within this range, however long the stay in space.
- Atmosphere. Present-day U.S. spacecraft provide a pure-oxygen atmosphere to breathe, at the low pressure of a little less than five pounds per square inch (absolute). This is about one-third of the normal atmospheric pressure (14.9 pounds per square inch), and is like that atop Mount Everest. But a breath of pure oxygen at five-pound pressure gives the lungs enough—more oxygen, in fact, than is in a breath of three-times-denser normal air (21 percent oxygen, 79 percent nitrogen).

The low pressure, besides saving spacecraft weight, gives space suits maximum flexibility to make wearers' movements easy. Using the same pressure in spacecraft cabins and space suits avoids complications in changing from one to the other—for a space walk, or in case a sudden failure of the cabin's pressure system forces the astronauts to close their helmets' faceplates and depend on the life-giving atmosphere in their suits.

As to how long astronauts can breathe pure oxygen without harm, however, there

[Continued on page 178]

It's Time to Put a Living Room in Orbit

[*Continued from page 85*]

is considerable argument. The Gemini 7 flight proved that two weeks is acceptable. But how about a year? No one really knows. Chances are that, for lack of experience, spacecraft or space stations designed for operating periods such as a year will go back to good old air—just to play it safe.

• Privacy. Many of us value the right to be left alone. After a year in space in crowded quarters, even the way the other guy eats, clears his throat, or tells a joke for the umptieth time can be trying.

Ground stations want continuous contact with an orbiting spacecraft, as with an airliner—and radio chatter is no lullaby to a man trying to sleep three feet away in a spacecraft. "Noise separation" for more privacy will be needed in the future. So will "light separation." Many cannot sleep with lights on. Today's astronauts may have no such problem, but some astronaut-scientists of the future undoubtedly will. Private quarters for the sleeping shift thus become a must.

A man wants to wash, shave, and attend to his other bodily functions in private—another reason for more generosity in the assignment of floor space in outer space.

• Food. Dehydrated and powdered food, reconstituted by moistening, kneading, and squeezing, may be fine for heroic explorers. But I think a man expected to perform at top proficiency in space for a year or more should get the same filet-mignon treatment as a business traveler on a supersonic flight from New York to Los Angeles.

• Entertainment. We all need diversion. A man cooped up in a space station or interplanetary craft will want something to listen to, or look at—whether it is the Beatles or Beethoven, *Playboy* or Plutarch. Advanced techniques offer ways to keep our space explorers happy and balanced: taped music, microfilm libraries, laser for interplanetary color television.

• Medical care. For a two-week trip to the moon and back, an astronaut need only check in with his flight surgeon for a prompt okay. But that will not suffice for a one-year stay in orbit, or a trip of years' duration to a planet. Anyone can have a toothache or catch a contagious disease, a few months after his doctor found him in perfect health. So it stands to reason that long stays in outer space will require a physician at hand—and astronaut-doctors

will become a part of the space-faring community, just as astronaut-astronomers and astronaut-meteorologists will.

- Gravity. Borman and Lovell were perfectly happy after two weeks of zero gravity. Their comments sounded almost as if their major concern was whether they would ever again get used to the nuisance of earth gravity—which makes you toss about in bed to find a restful position, while in space you could fall asleep and awaken hours later without having moved one bit. But medical men still do not know what a year of zero gravity will do to a man.

In case all he needs is physical activity, it can easily be provided, by devices like rowing machines or spring exercisers.

If it does turn out that long exposure to zero gravity has detrimental effects, a body centrifuge can straighten things out again. Operated by electric power, or by pedal power supplied by the astronaut himself, it will obviate having to spin the entire craft to replace gravity with centrifugal force.

Plenty of room. We shall have no problem in providing room enough for all these possible needs of extended space missions.

Saturn launch vehicles, designed to boost Apollo spacecraft to the moon, have huge liquid-hydrogen tanks in their upper stages. These tanks are empty on arrival in orbit. After being vented to the vacuum of space, they are clean as a whistle, free of odors other propellants would leave, and pressure-tight. They may then be filled with an atmosphere of pure oxygen or of any desired oxygen-nitrogen or oxygen-helium mixture. They provide ample room for a spaceman to "pitch his tent" in complete privacy—and can accommodate a kitchen, a doctor's dispensary, a shower bath, a men's room, a library, or anything else an astronaut on a one-year stint could desire. In a trial under NASA study that would make a spent 21-foot-diameter Saturn S-IVB stage habitable for 30 days, an Apollo spacecraft would dock with it, using a module providing a connecting airlock and an oxygen supply for the stage's interior. (The Saturn S-IVB stage serves as the second stage of a Saturn IB rocket, for earth-orbit missions; and as the third stage of a Saturn V moon rocket, for lunar injection.)

I think it is fair to say that the time has come when we are ready to break down the comfort barrier in space. PS

SEPTEMBER 1966 35 CENTS

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MONTHLY

Which Oil Is Best for Your Car?

Neglected Treasures of the Sea
By JOHN STEINBECK

600-M ... Jet
Hove

- 7 Ways
- Mario Andretti

In these space lifeboats, astronauts await arrival of rescuers from earth

Emergency Cocoon (above, left), under test by General Electric, shelters shipwrecked spaceman in an inflated fabric ball, heat-insulated by outer layers of aluminized plastic. Thin silicone-rubber lining retains oxygen carried for breathing, but lets unwanted carbon dioxide and water vapor escape.

Separable Shelter (above, right), proposed by North American, expands to hold five to 15 men and can serve as life raft for large space vehicles of future. Rocket self-propulsion can boost it higher, into longer-lived orbit that allows more time for rescuers to arrive.

LIFEBOATS IN SPACE

We're planning how we'll rescue stranded astronauts when, some day, an SOS comes from a manned spaceship in distress

By
Dr. Wernher von Braun

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

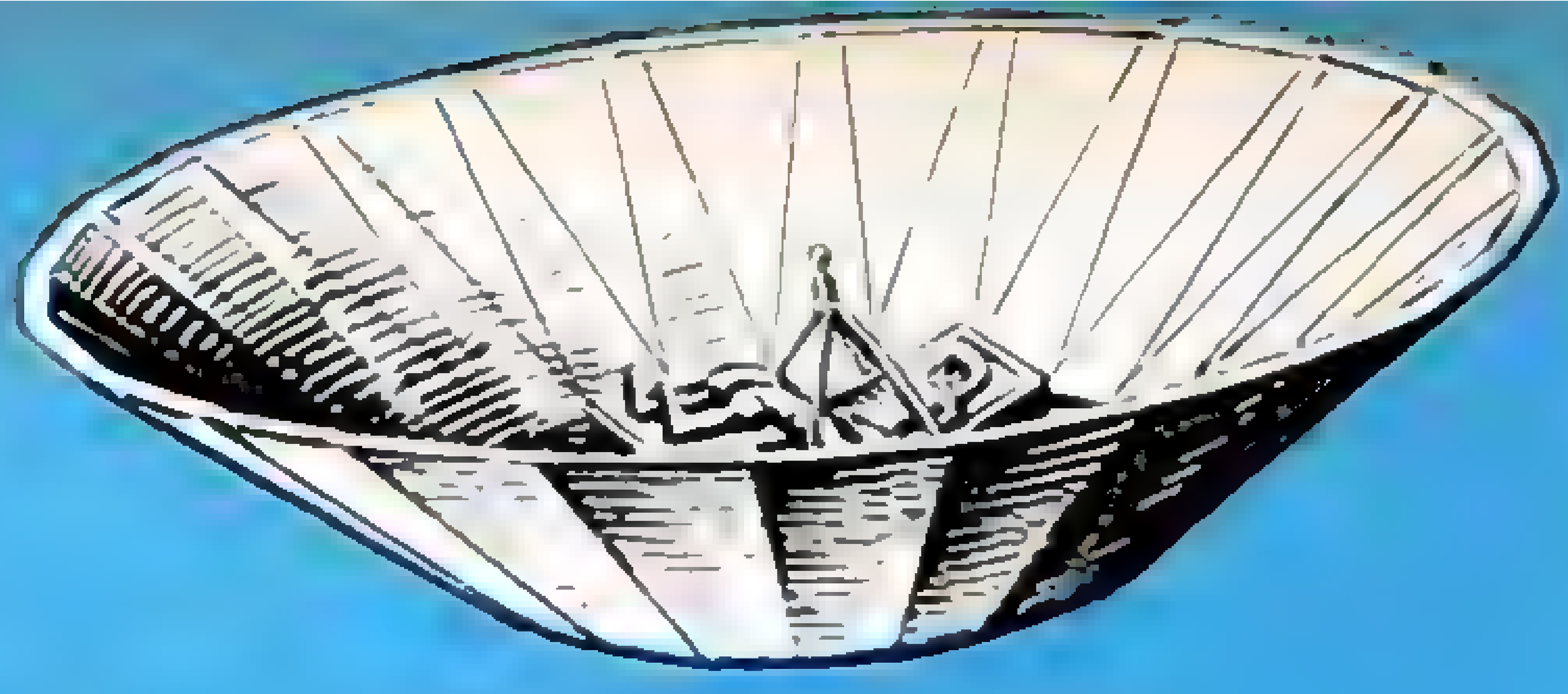
Sooner or later, we must be prepared to hear an SOS from the crew of a manned spacecraft in distress. What can we do to rescue the astronauts?

To date, our safety record in manned space flight has been outstanding. High standards of mission planning and control and of rocket and spacecraft design, plus superb astronaut selection and training, have spared us a space-flight tragedy. But as our objectives get bolder, as missions become more frequent and longer, and as ever-larger crews become involved in them, the chances are high that statistics will one day catch up with us. The close shave that the Gemini 8 crew had last March, when a runaway thruster threw their craft into a violent tumbling motion, has spurred demand for an active Space Rescue Program.

In many ways the problem of space rescue resembles the age-old problem of rescuing sailors from the sea. Emergencies may be much the same—equipment failure, illness or injury of a crew member, fire or explosion, a navigational error or collision. The resulting space-rescue tasks, like sea-rescue operations, may range from the relatively easy to the near-impossible.

A spacecraft crew marooned in a low orbit around the earth by retro-rocket failure is in a situation comparable with that of an offshore fishing party that cannot get the boat's engine restarted. The yacht can request assistance from a Coast Guard cutter, alerted by ship-to-shore radio. Even if the boat is rapidly sinking, or afire, lifeboats or life rafts offer an excellent chance of survival. For orbital flight, to be sure, neither Coast Guard cutters nor lifeboats are yet in existence—but they are entirely within reach of existing technology, and may indeed become available in the not-too-distant future.

At the other extreme, in the range of space-rescue difficulty, are future voyages across vast and empty space to other planets. Rescue from mishaps on such extended missions can only be based on the general pattern set by the great explorers of the sailing-ship age. When Colum-



These lifeboats bring a spaceman down

Space Parachute, a Douglas concept, offers a spacesuited astronaut an ejection seat with retrorocket for de-orbiting (left). Then conical drag skirt deploys (above) for self-stabilizing reentry, and landing cushioned by crushable nose. Because of light load per unit area, no heat shield is needed.

Self-rescue MOOSE (below), a General Electric idea, encases astronaut in a plastic bag that fills with polyurethane foam to assume reentry shape. He uses retrorocket to de-orbit, and then discards it. Bag has foldable heat shield for reentry, and parachute that automatically unfurls itself for landing.

bus lost his Santa Maria in a shipwreck at newly discovered Hispaniola, he transferred himself and her crew to the Nina and Pinta for the return voyage.

Obviously, a capability for space rescue did not and could not exist for the pioneering orbital flights. Our Mercury program was designed to prove that man could live and perform in space, with his proficiency not greatly impaired by zero gravity. It remained for subsequent Gemini flights to show the feasibility of orbital rendezvous and docking, a prerequisite for any scheme of rescue from the ground. And even the Gemini successes in rendezvous and docking do not mean that all we need to do for ground-based rescue is to hold a Gemini poised in constant readiness on its Titan II launch pad at Cape Kennedy. The problem is not as simple as that.

An orbit is fixed in space. The launch pad at Cape Kennedy whirls around the earth's axis, once every 24 hours. For a rendezvous to be possible, an ascending "chaser" rocket's course must lie in about the same plane as that of its previously orbited target—and that will happen only if it is launched during infrequent and brief periods, called launch windows.

Astronauts in the trouble-stricken target spacecraft may therefore have to wait

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Lifeboats in Space

[*Continued from page 97*]

many hours before the "Coast Guard cutter" can leave port. Bad weather, in the launch or emergency-abort area, and other factors may further delay a rescue effort.

A dogleg into orbit? Extremely powerful rockets such as Saturn V theoretically could execute a dogleg maneuver from a launch at the Cape into a target orbit in a different plane. This could substantially prolong the launch windows—or, to put it the other way around, could shorten the time the party in distress would have to wait for rescue. But, aside from the high cost of such a rescue operation, the time required to get a large and complex launch vehicle off the ground might well offset the gain of the wider launch window.

Not every orbiting spacecraft, unable to de-orbit because of retrorocket failure, will actually be in a hurry for rescue. As long as oxygen for breathing holds out, the crew can wait until help arrives.

Unfortunately, however, a careful analysis of space-rescue needs show that a substantial number of potential emergencies are likely to be urgent. If the crew does not get help at once, it will be too late.

A fire in a spacecraft is an example. The artificial atmosphere of present-day spacecraft consists of pure oxygen. An electrical short may cause a flash fire, disabling the craft's delicate electrical network within seconds. While the astronauts may be protected by their space suits, and may extinguish the fire by depressurizing their cabin, their craft may not be inhabitable.

The same result may follow penetration of the spacecraft by a heavy meteoroid; collision of two spacecraft in an attempted rendezvous maneuver; pollution of the cabin atmosphere with offensive or toxic fumes, released for instance by rupture of a hydraulic-pressure sensing line; and a mishap with a nuclear electric-power source, creating a radiation hazard in the craft.

Abandon ship! The urgency of spaceflight hazards like these has led many planners to propose the time-honored idea of the lifeboat as the best answer. For outer space, of course, the first and foremost requirement of a lifeboat is to furnish the shipwrecked astronauts with a shelter containing a breathable atmosphere, away from their stricken spacecraft.

Space lifeboats to shelter astronauts tem-

Continued

porarily, while they await rescue from the ground, are envisioned by some designers. To this category belongs General Electric's Emergency Cocoon, an inflatable spherical shelter, with heat insulation and provision for ridding exhaled air of carbon dioxide. North American Aviation proposes Separable Shelters, also stowable and inflatable, but a little more elaborate; they are equipped to propel themselves from lower into higher and therefore safer orbits.

Self-rescue ideas. Other suggestions call for lifeboats with full reentry capability. In this class belong the Douglas Space Parachute and General Electric's MOOSE (for Manned Orbital Operations Safety Equipment). Both fold for storage in a spacecraft, and both combine the characteristics of a life raft, a space-suit overcoat, and a cocoon.

Devices like these offer the obvious advantage of independence of ground-launched help. However, safe reentry and descent to earth do not assure survival. An uncontrolled reentry could land the space lifeboat in an inaccessible area, or on a windswept ocean. Self-rescue devices must therefore be provided with communications and tracking equipment, light beacons, and survival and flotation gear.

Will we be able to rescue future explorers stranded on the moon?

Our Apollo program provides the astronauts with a great variety of "abort options," should something go wrong during the many phases of a voyage to the moon and back. But if an Apollo landing party were unable to return from the moon to the mother spacecraft left orbiting around it, any attempt to rescue them from the earth would simply come too late.

In an advanced stage of lunar-surface operation, however, things will be quite different. Just as Arctic explorers can survive an entire winter in the freezing cold, future lunar explorers can be provided with temporary shelters and enough supplies to await rescue for weeks or months, if need be. Moreover, just as Surveyor 1 soft-landed television equipment at a precisely predetermined spot on the moon, it is entirely feasible for unmanned craft to deliver everything needed for survival to a stranded lunar expedition of the future, until a relief party can reach it. These supplies may be dispatched either from a lunar base, or from the earth direct. PS

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MONTHLY

Complete Facts and Color Photos of the '67 CARS

SPECIAL!
Unique
CAR-SELECTOR GUIDE
Tells Which
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For You

SEE PAGE 87

CAMARO, Coming and Going

HOW GOOD IS THE NEW CAMARO?

Exclusive Road Test by MARIO ANDRETTI

ARTHUR GODFREY Tells How He Flew Around the World in 86 Hours

It's Easier Now To Build Good Furniture!

These implements for spacemen solve weird problems of making repairs in zero gravity, vacuum, temperature extremes, and pitch darkness

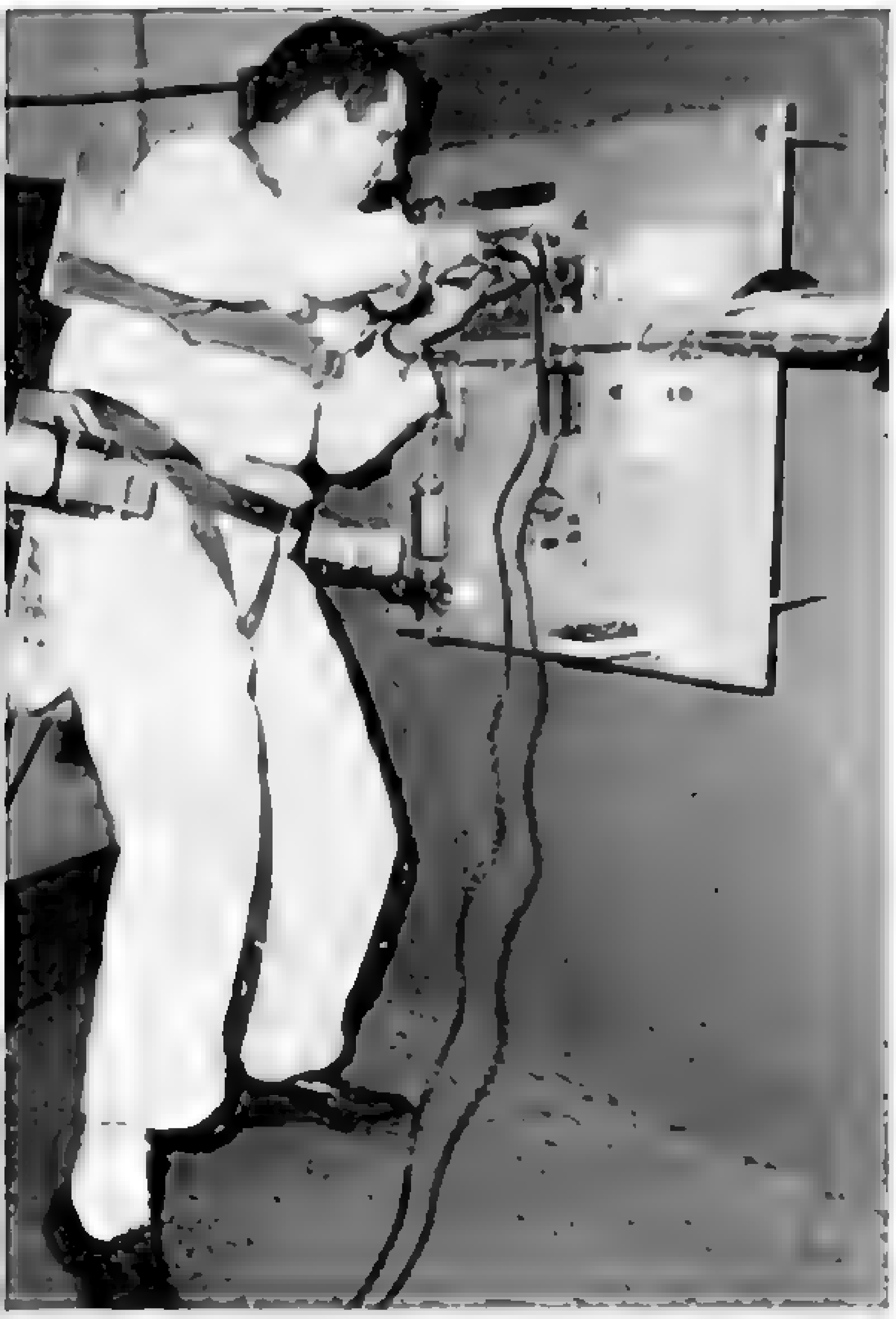
ASTRONAUTS GET

NASA's tool kit for repairs in space offers these aids. Below battery-holding toolbox are power tool (with electric cord) fitted as impact wrench, and drill and saw attachments. Other items include lamps for helmet (below toolbox lid), and artificial fingernail, worn on pressurized glove, to help grasp small parts.

A TOOL KIT

By DR. WERNHER VON BRAUN

Director of NASA's
George C. Marshall Space Flight Center,
Huntsville, Ala.



Moon's low gravity is simulated for space-tool trial by rig taking 5/6 of subject's weight off his feet.

Scuba diving gear and water-filled tank give effect like zero gravity in orbit, as subject removes a bolt.

Future repairs, maintenance, and assembly work in space will require tools designed for unearthly working conditions. They must work reliably in a vacuum, and at extremes of temperature. They must be usable by a man encumbered with a space suit and pressurized gloves—and must enable him to tighten a nut or saw a piece of spacecraft skin without putting himself into a tailspin. Despite these stiff requirements, space tools must be extremely light.

The problem of reliability, or rather the lack of it, of a complex spacecraft's many small parts has plagued our space program from its beginning. With the advent of manned space flight, the possibility was considered of giving astronauts a limited capability for maintenance of a spacecraft.

Should astronauts be repairmen? If a part failed, went the reasoning, why not replace it with a spare? It sounded attractive until engineers, eyeing details, ran into snags. How many tools does it take to change a fair number of parts? How does an astronaut check a repaired pressure line for leaks—or make sure a subsystem with a replaced part will work properly, short of turning it on? Difficulties like these led to a sweeping but well-founded policy decision for the entire U.S. manned space-flight program: "There will be no inflight maintenance."

Yet, as missions grew longer and more complex, the desire to perform simple repair jobs, at least, was bound to reawaken. If something got bent in docking too fast, or if a hatch to scientific gear wouldn't open after a successful but rough lunar landing, an astronaut would want to get out a tool kit and do something about it. Like changing a flat on a car, this sort of thing was not really a maintenance task.

A space repair kit. And so NASA now has a tool kit for astronauts, after all. Developed for the Manned Spacecraft Center by the Martin Company, in cooperation with the tool firm of Black & Decker, the Space Tool Kit forms a completely integrated package 14 inches long, 14 inches wide, and 10 inches high. Its metal shell has a rigid foam liner in which pockets have been cut to hold the tools and accessories.

Its centerpiece is a multipurpose power tool with a pistol grip. Interchangeable attachments convert the tool into an impact wrench, drill, or metal saw. A five-pound, 12-volt rechargeable battery, built into the toolbox, serves as the DC power source.

The innards of this deceptively simple-looking tool

[*Continued on page 220*]

Astronauts Get a Tool Kit

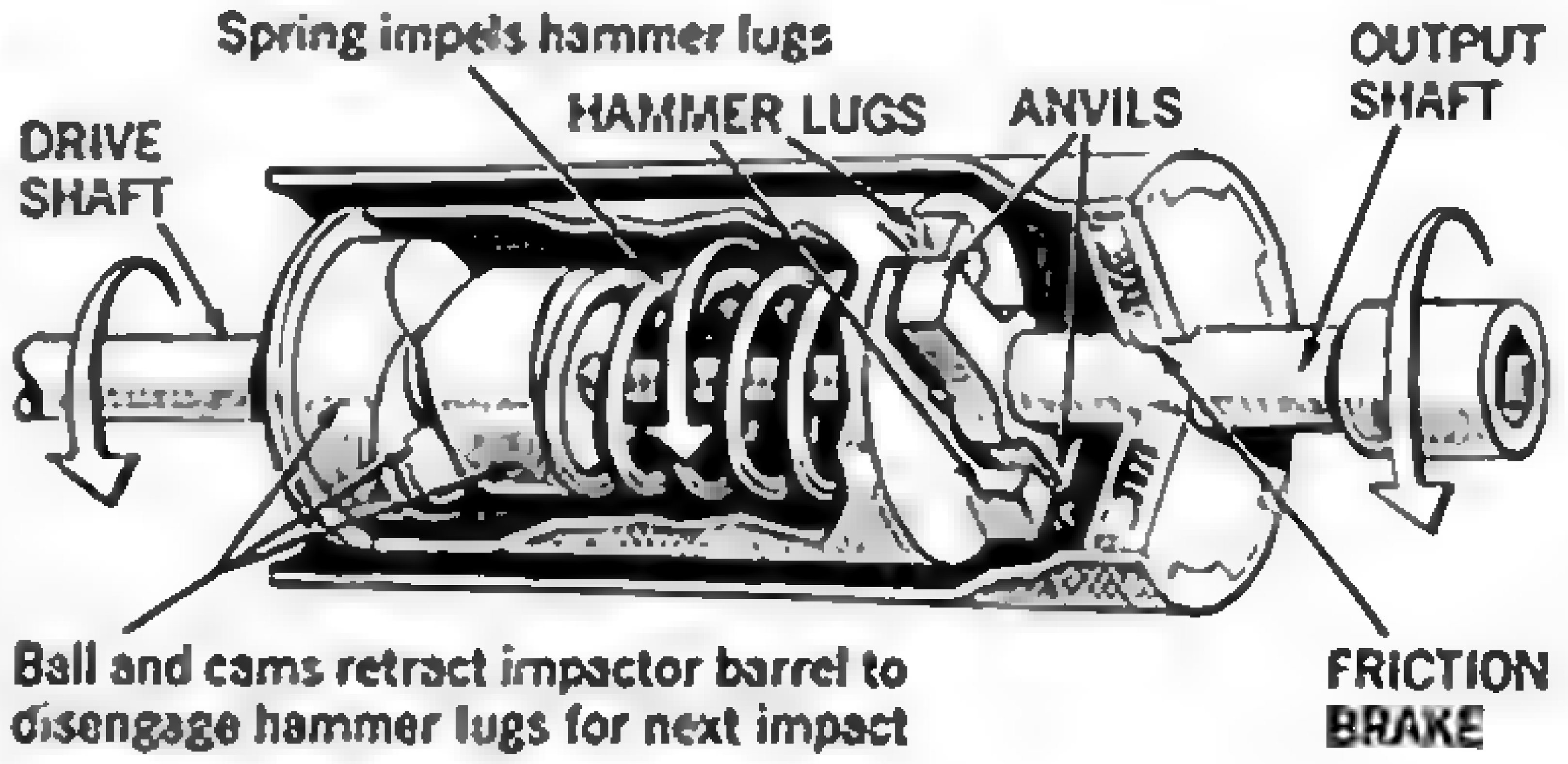
[*Continued from page 147*]

meet exacting requirements. Since there can be no air-cooling in the vacuum of space, the tool must absorb and radiate its heat. Ordinary lubricants would evaporate rapidly, especially from warm surfaces; silicone grease is the answer. Metal surfaces tend to cold-weld, when forced together in the absence of oxygen; the saw design avoids this. Though heating conditions vary greatly in sunlight and shade, the pistol grip remains at a temperature compatible with the glove that grips it, during extended use of the tool.

The astronaut himself poses even greater problems than does the environment. When he turns a nut with an ordinary wrench, an equal turning force or torque acts upon him, in the opposite direction. If he were under zero gravity and without a firm foothold, the nut probably would not budge at all—and he would succeed only in spinning himself the other way around.

A wrench for use under zero gravity (as in orbit) or under low gravity (like the 1/6 G on the moon's surface) must eliminate or minimize this reactive force. It will do so if it can be squeezed, instead of turned, but its tightening force will then be limited by the strength of the astronaut's grip. A power tool, to avoid reactive torque, must have a "closed force path" like that of a squeeze wrench.

Reaction-free impact wrench. Through a clever mechanism, patented by Black & Decker, the Space Tool Kit's impact wrench provides such a closed path. The electric motor twists and releases a spring about 3,000 times a minute. Hammer lugs, spun by this spring, impact sharply against anvils to turn a friction-braked output shaft, as pictured below. Thus a completely reaction-free pulse of torque is available to tighten that loose nut. The pulses exceed by many times the steady torque that either the astronaut's muscle power or the



Astronauts Get a Tool Kit

motor in the tool would be able to apply.

Even with a reaction-free tool, a man floating freely in front of his work under zero gravity would not be very effective. Therefore the Space Tool Kit includes a restraint system. Disks about an inch in diameter, glued to the outside of a spacecraft in flight, provide anchors for wires to tether an astronaut. Three wires will hold him firmly; in some cases two, or even one, will suffice. (On the moon, he will not need to anchor himself at all.)

Since Band-Aid-type adhesive would not do under the extreme conditions of outer space, each restraint "button" has an epoxy surface, with electric heating wires embedded in it. Heating the epoxy bonding agent for about 30 seconds, while pressing the button against the spacecraft's skin, establishes a firm anchor point that will sustain a pull of up to about 50 pounds.

Lamps like a miner's. In space, lack of a light-scattering atmosphere results in extremely harsh contrasts between light and shadow. Working inside dark areas of the spacecraft, accessible only from the outside, is impossible without artificial lighting. After experiments with sunlight-reflecting mirrors, and lamps attached to wrist or body, the most satisfactory solution has proved to be mounting lamps on each side of the astronaut's helmet—a variation on the idea of a miner's headlamp. Helmet lamps are therefore included in the Space Tool Kit.

A problem of major concern was eliminating the hazard of explosion and fire when the kit was used in the crew compartment of a spacecraft—which is filled at low pressure, five pounds per square inch absolute, with pure oxygen. Extensive test runs in this atmosphere finally led to arc-free electric-motor brushes, and switches that couldn't spark a fire.

Other problems solved to everyone's satisfaction included restraining loose parts like bolts from floating away in zero gravity, and adapting tools to be handled with the limited dexterity of pressurized spacesuit gloves. An "artificial fingernail," for a gloved finger, aids in manipulating small objects.

While the Space Tool Kit will serve for simple repair jobs, future manned missions will undoubtedly pose the task of assembling large structures in space. These may

Continued

Astronauts Get a Tool Kit

include big dishes for radio communication and radio astronomy; and interplanetary space vehicles, ferried up in sections by earth-to-orbit carrier rockets.

Know-how on way. Assembly jobs like this will require novel fabricating methods, particularly suited to use in space.

NASA's Marshall Space Flight Center has conducted an extensive survey of suitable techniques. Electron-beam welding, a new high-quality method requiring a high vacuum around the weld, proves extremely promising. So does cold welding, which applies the fact that metal surfaces, properly cleaned, will bond together even at room temperature in a high vacuum.

Another Marshall study involves electroforming. When a high-energy electrical pulse surges through an electromagnet, a piece of aluminum can be shaped by the impact of the strong magnetomotive force, as if by a forging press. In outer space the electric energy can easily be collected with solar-cell batteries and stored in capacitor banks. Abruptly discharging these banks will yield strong electric pulses and magnetic fields, which can be put to good use in assembling large space structures. For example, the magnetomotive force created by a single discharge through a sleeve-shaped magnet, slipped over the telescoped ends of two sections of aluminum tubing, can join them inseparably.

All space tools, and all assembly operations in space, require advance studies and crew training in simulators. For realistic planning, questions that must be answered beforehand include the accessibility of operating stations, the time needed to complete a task in a full-pressure space suit, and the metabolic rate of the test subject while doing the job.

Simulating reduced gravity. Tests in water-filled tanks, with subjects using scuba diving gear, have helped to investigate problems of space-tool use under zero gravity. In experiments to study working on the moon, its low gravity is simulated by supporting five-sixths of a subject's weight with a fork-shaped arm, so that only one-sixth of his weight rests on his feet. As expected, it turns out that the force he can exert without losing his foothold is reduced to one-sixth of what he can apply when his feet support his whole weight under normal one-G gravity. PS

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STEVE McQUEEN on the bike he built for himself

Dr. von Braun (center) hails success of simulated 18-day moon mission by MSFC engineers H. Y. Grubbs (left) and M. J. Vaccaro.

Action-packed plans for exploring and sampling the lunar surface will make the most of astronauts' exciting opportunities to solve its mysteries

By DR. WERNHER VON BRAUN

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

What

Our astronauts' first landing on the moon is now probably less than a thousand days away. What will they do when they get there?

Even the earliest and briefest missions will begin an exciting program of exploration to solve long-standing mysteries of the moon. This many-faceted program will later reach full swing when more-advanced spacecraft enable explorers to remain longer on the moon, and to make extended journeys across its surface.

The first comers. New details of what our first Apollo landing party will do, when the two astronauts have left their three-man mother ship in lunar orbit and set down their landing craft on the moon, have just been made public by NASA.

From touchdown to liftoff

Battery-powered core drill, a prototype of portable tool for cutting sample from solid rock on moon to bring back to earth, gets a trial at NASA's Manned Spacecraft Center in Houston, Tex.

First astronauts on moon will leave instrument package like this to send data after they're gone. Its carrying bar becomes a mast for radio antenna.

On moon's surface, instrument package will be spread out, as rehearsed here with mock-up. Black object at far right represents its atomic battery.

We'll Do on the Moon

they will remain on the moon for 18 hours. Twice, both astronauts will emerge from a hatch of the Lunar Module, their landing craft, and venture together over the lunar surface—for three hours each time. The rest of their stay will be taken up in check-outs of their craft and life-support gear, communications, and a six-hour period for eating and sleeping between trips outside.

Sampling the moon. Collecting samples of moon rocks and soil, to bring back for study, will be a major activity of their six hours of exploring. They will take photographs of the lunar terrain, too, and inspect and measure the "footprints" of their own craft in the lunar soil. Finally, they will spread out on the lunar surface, a safe 300 feet away from their point of takeoff, an array of scientific instruments that will automatically radio information back to earth for at least a year after they have left the moon.

A mock-up of this Apollo Lunar Scientific Experiment Package (ALSEP) was recently demonstrated at NASA's Manned Spacecraft Center in Houston. It includes a variety of instruments to observe the lunar-surface environment, and others to probe beneath—by such means as a grenade launcher to produce artificial seismic waves, and a seismometer to detect them. An atomic battery called SNAP-27, being developed especially for ALSEP, will be the 50-watt thermoelectric power source. The astronauts will insert its plutonium fuel capsule after landing on the moon.

Moon mysteries to solve. From this modest beginning will unfold a vast project of lunar exploration designed to answer questions as varied as these:

Are there living organisms on the moon—perhaps completely different from any on earth? Microbiological experiments on lunar samples, from the surface and below, should tell. Likewise to be sought in the samples are primeval organic substances, like those from which life originated on earth—and oxygen and traces of water that might be extracted from lunar materials to help support future bases on the moon. Geologists will be eager to identify the lunar minerals themselves, and deduce the manner in which they were formed.

Is there a trace of a lunar atmosphere, and how much? Since it must be so tenuous that even Lunar Module rocket engines may contribute substantially to it, scientists urge beginning its study as near as possible to the start of the Apollo program.

What is happening in moon craters, like Alphonsus, that show signs of activity? These "thermally active" craters, the maria or "seas," and the cratered high-lands will be the three main types of lunar terrain of interest to explorers.

How was the moon born? Was it torn from the molten earth by solar gravity,

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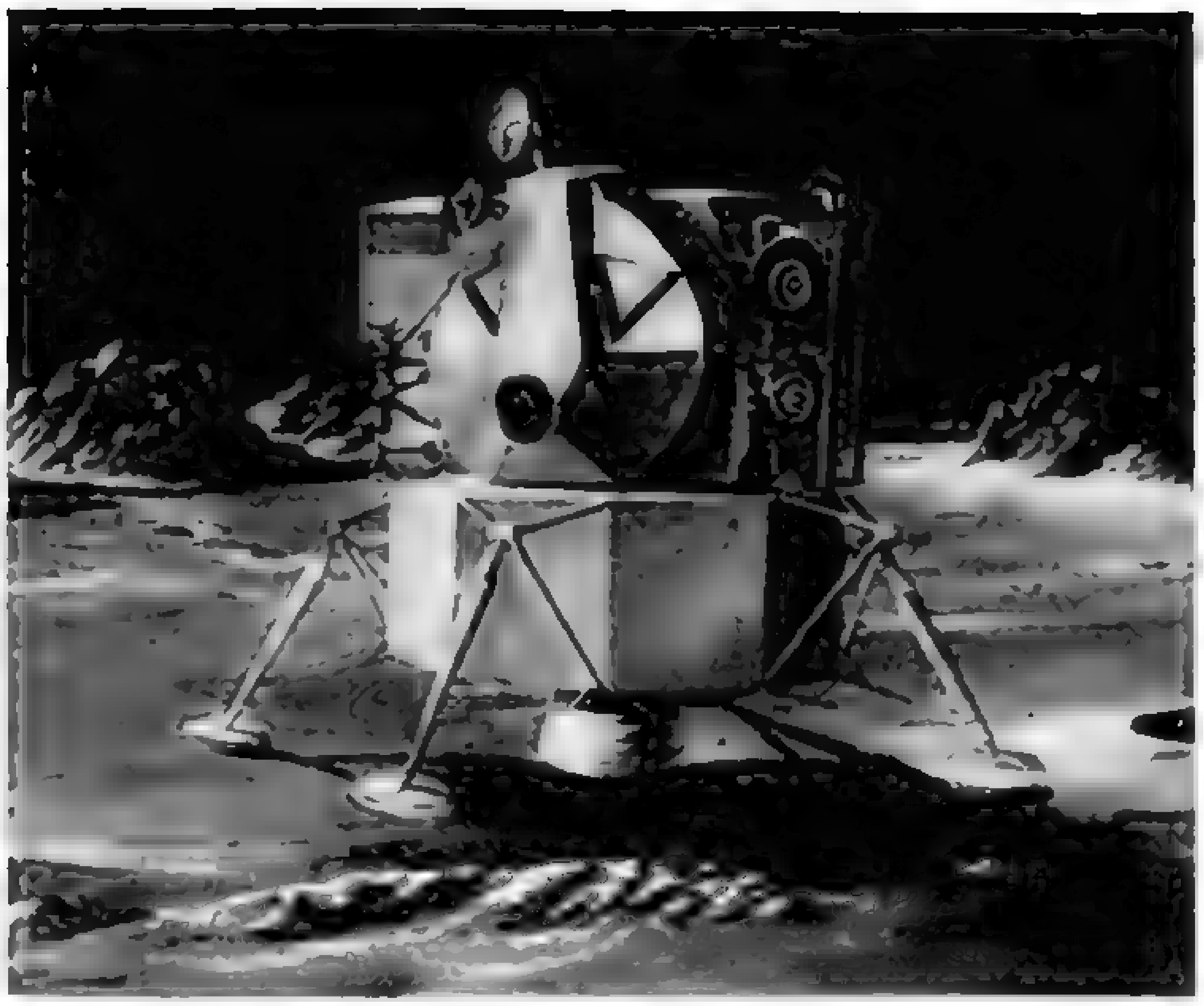
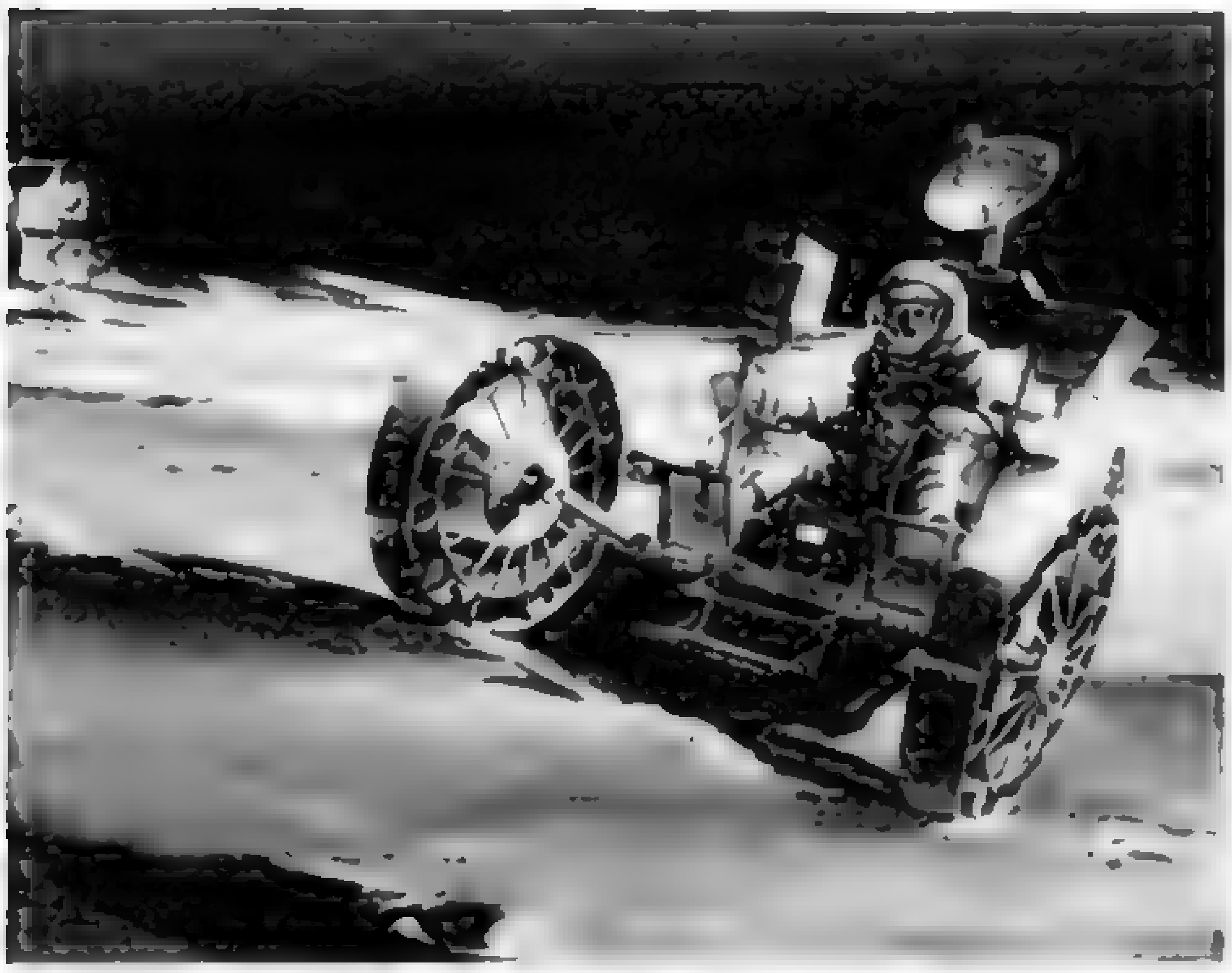


LM Shelter, an unmanned and modified Lunar Module landed on moon before astronauts' touchdown, could become their base for two-week stay. This is one of plans being weighed for extended missions.



This "Lunar Jeep" could be brought to moon on outside of LM Shelter. Moon vehicles will extend explorers' range, and give access to interesting features in terrain too rough for safe landing.

Unmanned cargo landers, launched by Saturn V rockets, could soft-land 30,000 pounds apiece on moon—opening way to large stationary and mobile lunar labs and, ultimately, permanent manned bases.

or did it and the earth condense from the same rotating gas cloud, or were moon and earth both built up from solid fragments orbiting the sun in disarray—the "accretion" theory now favored? Investigating the moon's history figures largely in a list of 15 key moon questions that the National Academy of Sciences, in close cooperation with NASA, has prepared. For this may well tell us more about the earth's own past. While our planet's birthmarks have been virtually eradicated by erosive forces like wind, rain, floods, and vegetation, those of the airless moon should be preserved.

Tools for moon explorers. Implements for answering such questions will include:

- Long-handled scoops to gather loose rocks, simple scales to weigh their load, and containers to seal them in.
- Drills to collect core samples, and probes to measure temperatures, in the outer 10 to 100 feet of the moon's crust.
- Seismic equipment to furnish information on the moon's interior structure.
- Magnetometers and gravimeters to measure local variations in the moon's magnetic and gravitational fields.
- Sampling containers and gas-analysis equipment to study the lunar atmosphere.

What's ahead? Early Apollo moon landings, limited to about 250 pounds of scientific gear, will not go far beyond the first landing in surface activities. These Lunar Modules will be unable to support a stay of more than 48 hours on the moon, and much of this time must be used to check out the craft for the flight back. Also, the stay must be limited to avoid fatigue. At the end of their two-week voyage to the moon and back, the crew will face the most strenuous, exacting, and critical maneuver of all—the precision approach and reentry into the earth's atmosphere at a blazing 36,000 feet a second, more than 24,000 m.p.h. Main emphasis will be on demonstrating the feasibility of the flight itself.

Follow-on flights with more-advanced spacecraft will permit much longer stays on the moon. Increased payloads will provide moon explorers with really sizable tools (like deep-drilling rigs) and with vehicles to make extended trips afield from the landing sites. Then will come the heyday of lunar exploration.

Advanced lunar-landing craft. One of two moon-landing concepts that look par-

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[Continued from page 92]

ticularly promising is called the Augmented Lunar Module (ALM). It applies the fact that the Saturn V launch vehicle seems capable of hurling toward the moon a somewhat higher payload than was originally specified. This would allow some increase in the propellant capacity of the LM and, in turn, an increase in the useful load landed by the LM. Thus the life support for the astronauts—oxygen, water, food—could be extended for several days. More scientific equipment could be carried along to make those extra days worthwhile.

The other concept envisions twin landings on the moon, by an "LM Shelter" and an "LM Taxi." It would work as follows:

Two Saturn V/Apollo space vehicles are launched from the Cape, maybe weeks apart. The first carries a normal Apollo Command and Service Module and the usual crew of three. Upon arriving in orbit around the moon, the crew detaches and dispatches a special unmanned LM—the LM Shelter—to a predetermined landing spot, and returns to earth.

A home on moon. This one-way LM Shelter consists of an unmodified LM descent stage, and an LM ascent stage from which the propulsion system has been removed. Hence it can land a payload equal to the full weight of a fueled and manned LM ascent stage (plus whatever weight a round-trip LM would leave on the moon).

A few weeks later, the second Apollo spacecraft appears in orbit around the moon. Two of its three astronauts transfer from the Command Module to the LM Taxi and descend to the lunar surface. The LM Taxi differs from a normal LM only in that it can survive the lunar environment for an extended time, without losing its capability of climbing back to the orbit around the moon.

Guided by a radio beacon on the LM Shelter, the LM Taxi touches down within a fraction of a mile from it. Then the Shelter becomes the astronauts' lunar base. They return to the Taxi to depart.

A major attraction of the Shelter-Taxi concept is that the Shelter offers a habitable abode for a stay of weeks. Removing the ascent stage's propulsion system leaves room for the astronauts to sleep in hammocks, for instance, rather than rest in the rather awkward squatting position required in a normal LM. They would be able to get out of their space suits during rest periods. The feasibility of such a stay was illustrated early this year by a simulated moon mission of comparable length. In a cabin about the size of three telephone booths, built for the trial at Minneapolis by Honeywell, Inc., two Marshall Space Flight Center engineers successfully lived and worked for 18 days, making space-suited excursions from time to time. Results of the test were equally applicable to the LM Shelter, or to a mobile and enclosed lunar laboratory (which the design represented).

Another advantage of the one-way LM Shelter, with its great extra payload, is that it can bring along a "Lunar Jeep." This vehicle would extend the astronauts' radius of action from one or two miles to easily 10 times as far.

An obvious disadvantage is that the Shelter-Taxi concept requires two successful landings at the same spot—while the Augmented LM provides a complete, if severely limited, scientific capability wherever it touches down. Views of lunar-surface features from Lunar Orbiter are expected to yield information that will help in choosing between the two approaches.

The next steps. In the long haul, lunar-surface exploration will call for more-advanced hardware, not included in the present Apollo program. For instance, if a Saturn V is employed solely to carry cargo on a one-way trip, to a predetermined spot on the moon, neither the manned Apollo Command and Service Module nor an LM is needed. Instead, the unmanned flight could follow the successful Surveyor soft-landing pattern, with a newly developed high-energy braking system used for the final letdown. Such a transportation system could soft-land payloads of up to 30,000 pounds on the moon.

This capability, entirely within the reach of a standard Apollo/Saturn V launch rocket, could truly put a new dimension in our lunar-surface activities. Mobile laboratories, capable of trips of several hundred miles across the face of the moon, would become a possibility. And permanently inhabited camps on the moon, comparable to our research camps in Antarctica, could become a reality within a few years after the first lunar landing. PS

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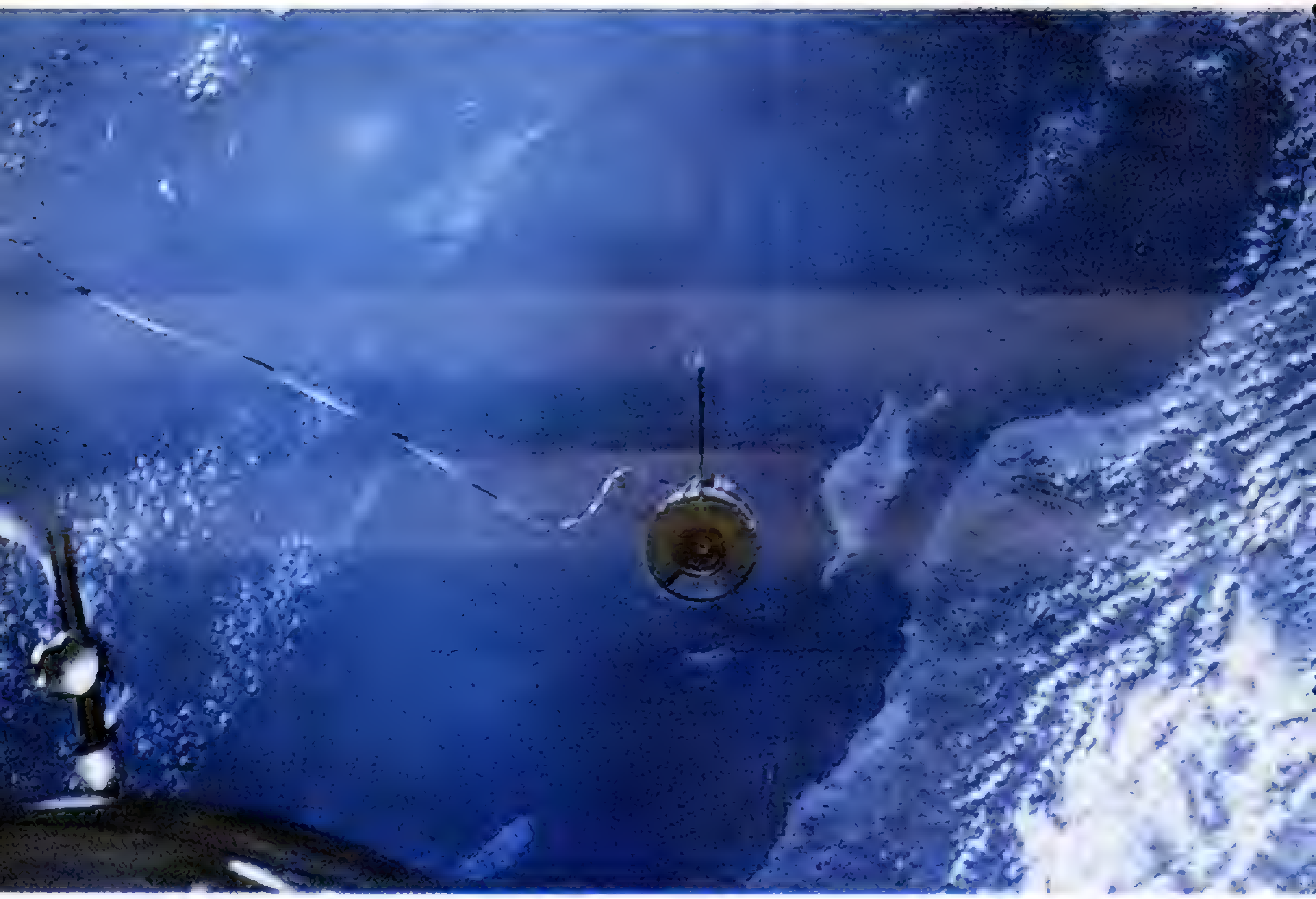
ELECTRIC AUTOS: They're on the Way!

By tethering two spacecraft and spinning them, Gemini 11's crew showed how astronauts could avoid the problems of living under "zero g" in space stations and interplanetary craft

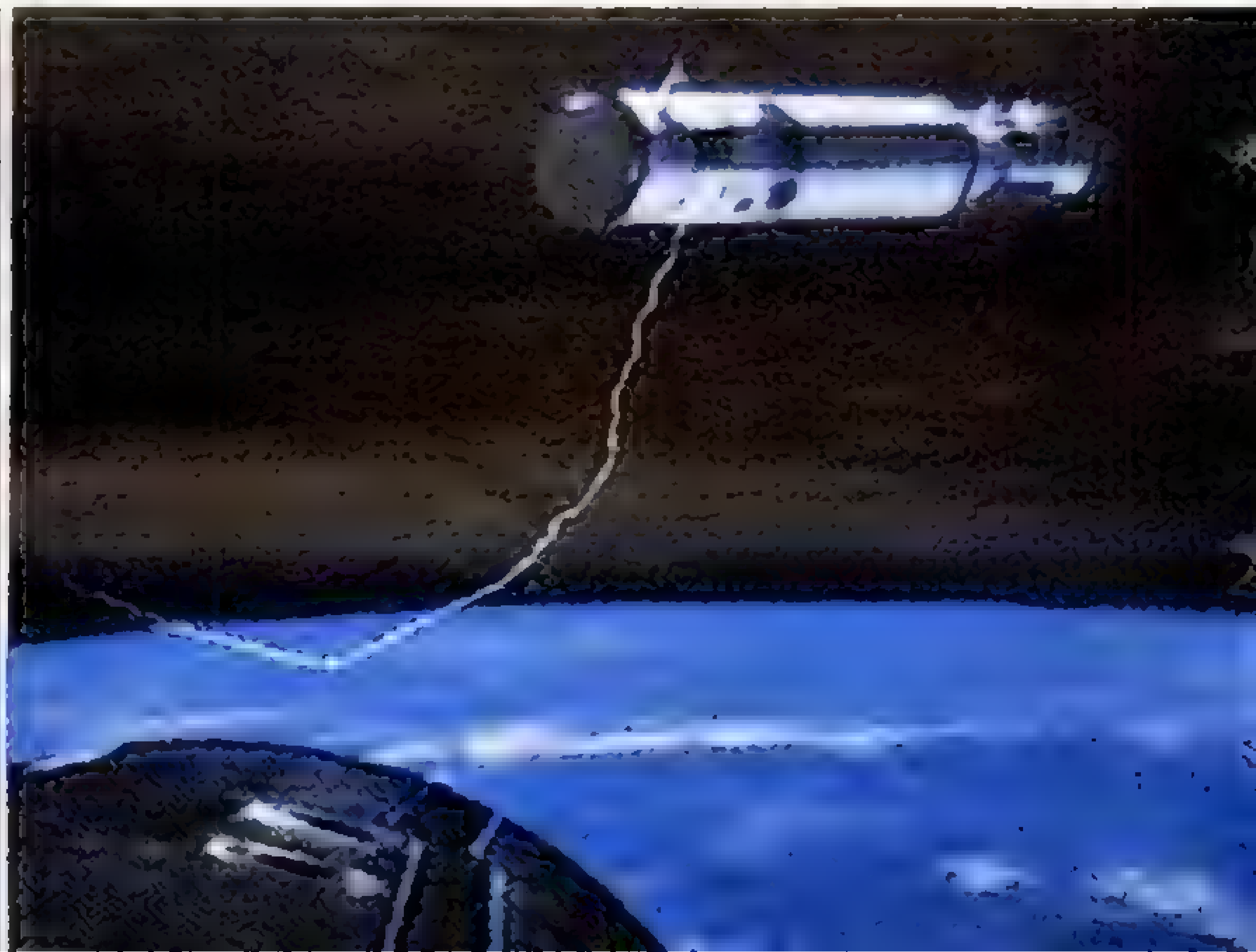
ARTIFICIAL GRAVITY FOR



Hundred-foot tether links Gemini 11 in foreground, backing away to take up slack, with Agena.

Tether begins to come taut for trial spinning of the linked vehicles, creating artificial gravity.

After successful test of artificial gravity and formation flying, Gemini 11 casts off the tether.



By DR. WERNHER VON BRAUN

Director of NASA's George C. Marshall
Space Flight Center, Huntsville, Ala.

ASTRONAUTS?

Last Sept. 14, two days after his Gemini 11 spacecraft had been injected into orbit, Lt. Cmdr. Richard F. Gordon emerged and attached to the Gemini a 100-foot line from the Agena target vehicle to which it was docked.

When Gordon was back inside, Cmdr. "Pete" Conrad, the command pilot, undocked the Gemini from the Agena and backed away to pull the line taut. Then, firing his control jets sideways, he imparted a rotating motion of about two degrees a second, or one-third of a complete revolution per minute, to the orbiting "dumbbell."

First artificial gravity. This slow rotating movement created a slight centrifugal force, equivalent to a gravity pull of about 1/1,000 of a *g*, that shoved the astronauts very gently back into their seats. For the first time, even though on a modest scale, artificial gravity had been created in a manned spacecraft.

The feat had taken tricky maneuvering. As the two-inch-wide tether line was being pulled from its storage bag on the Agena, the resulting tugs on that craft repeatedly made it yaw around. Finally the Gemini drew the tether taut—but it took quite a while for the Agena to stop its oscillations and line up steadily with the tether. Even after a spin was imparted to the dumbbell configuration, the centrifugal acceleration did not steady down to a constant value at once, because the elastic Dacron-webbing tether line behaved like a spring and kept contracting and expanding for a considerable time.

Conrad and Gordon completed about 2½ orbits around the earth in the slowly revolving configuration. They proved that two spacecraft in orbit can be tied together with a long rope—and that a slow rotation can effectively prevent the two craft from getting tangled up or colliding with each other. This means that extended formation flying in orbit will be possible without a prohibitive expenditure of propellants for "station keeping."

The experiment proved, too, that the low centrifugal force resulting from the spin is acceptable and does not result in discomfort for the crew.

Unanswered questions. In this pioneering trial, however, the spin was too slow and the centrifugal acceleration too weak to answer these long-asked questions:

Is spin-induced centrifugal force an adequate substitute for the missing gravitational force in unpowered orbital flight? And, indeed, is artificial gravity desirable at all?

Early concepts of manned space stations provided for spin-induced artificial gravity, because of the complete lack of knowledge as to whether a human being could stand prolonged weightlessness. Flights through "ballistic trajectories" in rocket- and jet-powered aircraft could simulate this eerie condition for a minute or two. But, without actual manned flights into orbit, it was impossible to find out whether zero gravity was going to prove acceptable for days, weeks, or months.

We know today, after Frank Borman's and Jim Lovell's 14-day flight in Gemini 7, that two weeks of zero gravity is not hazardous and does not impair pilot proficiency. But we still cannot say whether zero gravity would be acceptable for permanent space stations, or for interplanetary voyages lasting for months. It is likely that spin-induced artificial gravity will be used for such projects.

The "whys" of artificial gravity. Considerations favoring artificial gravity are partly medical, partly practical.

Among the most fabulous sensing devices in the human body are the vestibular organs of the inner ear. They consist of two major subsystems: The semicircular canals are filled with a liquid and, as you nod your head up or down, the tiny pres-

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Artificial Gravity for Astronauts?

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sure difference between the ends of the canals generates a signal to the brain that indicates angular acceleration. The otolith apparatus is a pebble-size bone embedded in a jellylike substance and floating on hairs. The hairs project out of sensory cells, and the signal of those hairs that report the greatest load from the otolith is accepted by the brain as the "down" direction. The otolith apparatus responds to linear accelerations.

The vestibular organs, we know, can be easily upset. Some people get dizzy on a merry-go-round. Some are subject to seasickness. Vertigo can play tricks even on experienced jet pilots.

Moreover, the effect of sudden zero gravity is known to throw the body into a state of alert. In everyday life, zero gravity means free fall—caused voluntarily if we jump from a diving board, or involuntary if we fall from a ladder. In either case a potentially dangerous impact is imminent—and the body is alerted to brace itself for it by the otolith's zero-gravity message to the brain.

What if there were no impact, and no all-clear signal either, after the otolith flashed its zero-gravity alarm signal to the brain? Some medical men feared dire effects on the proficiency of astronauts, prior to man's first ventures into outer space. We know now that this problem does not exist—at least not for experienced pilots who have been through many limited periods of zero-g.

They like zero-g. In fact, all our astronauts have commented that if zero gravity posed a problem at all, it was the feeling of extreme comfort—which tended to induce sleep and made it a little harder to stay wide awake during periods of little activity or excitement. Possibly the greatest readjustment problem was getting used to normal gravity again, particularly after splashing down in the ocean and being tossed about by the waves.

Medical studies indicate that prolonged zero gravity does have some physical effects, quite similar to those of extended rest in bed. For example, the body's lower extremities act as a pool in which much of our blood supply is kept by gravity when we are standing upright—but they do not do so either in bed rest or in zero gravity. On

Continued

the average, therefore, the heart has to pump more fluid when we are lying in bed, or are in zero gravity.

As a result, the heart flashes a signal to the kidneys to extract some of the blood's water, which is excreted as urine within a day or two. At the end of the bed rest, or exposure to zero gravity in space flight, the blood volume is promptly restored by an urge to drink water.

Gravity's handy. Practical considerations may offer more reason for introducing artificial gravity in space stations and interplanetary spacecraft. When dirt doesn't fall to the floor, but keeps floating in midair, it can get awfully messy after a while. A spacecraft cabin may be spick-and-span and surgically clean at takeoff. But after several weeks of eating, drinking, conducting scientific experiments, and unpacking and storing auxiliary equipment—not to speak of the functions of body hygiene—things can become pretty clammy. Under artificial gravity, you can fry an egg in a pan, lay a book on a table, vacuum the floor, take a shower, and lead a normal life.

Even more important, under artificial gravity you can use research equipment designed for normal earth laboratories. You don't have to redesign it to make it compatible with the zero-g environment of a space laboratory.

The first scientists have already joined our astronaut program—but, today, the demands for physical qualifications are still high. Astronautics is still in the experimental stage, and any astronaut should be capable of withstanding the physical strains of sudden emergencies.

A decade ago, jet aircraft were something for professional pilots to worry about. They have now been invaded by grandfathers, elderly ladies, and babies, while parachutes have been replaced by television, stereo music, and fancy food service.

A decade from now, most of the inhabitants of a space station will be astronomers, bioscientists, medical researchers, engineers, and meteorologists. Today's astronaut will have moved up into the role of station commander or member of his staff. And as space activities come to include more people from normal walks of life, artificial gravity will be the popular thing to have—because it makes life in space more like life at home. PS

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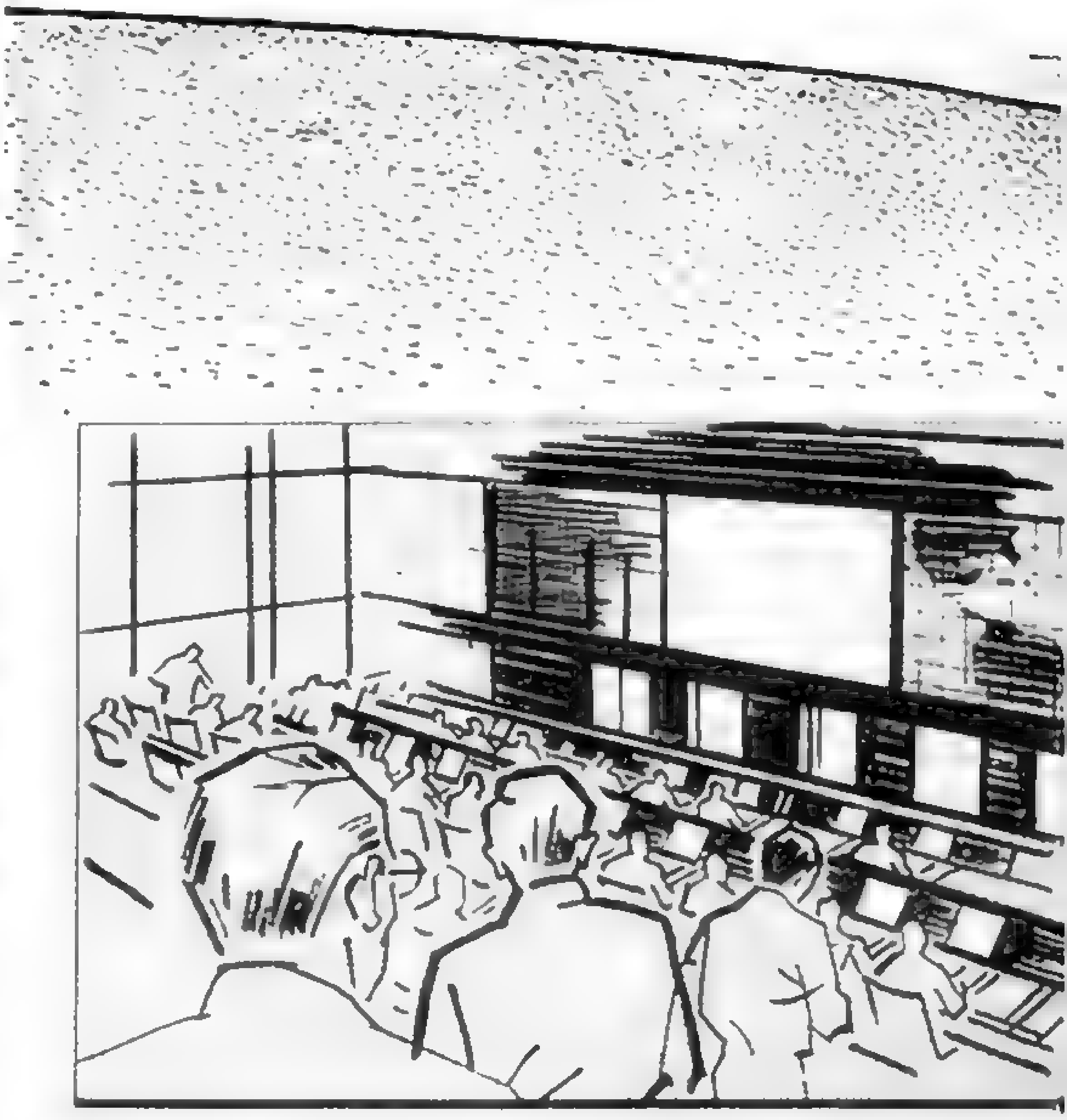
Sea-and-Air Armada

Dr. von Braun, left, outlines to PS Editor-in-Chief Ernest V. Heyn the plan for the voyage to the moon that will climax the coming series, succeeding Gemini, of three-man Apollo space flights.

Electronic ships and planes will link astronauts with earth at critical moments of lunar voyage

By DR. WERNHER VON BRAUN

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.



An armada of ships and planes, deployed around the globe, will relay commands and flight data at critical moments of our Apollo astronauts' flight to the moon.

The sea and air stations will complete a new communications network being set up for our three-man Apollo space flights—which now succeed our completed one-man Mercury and two-man Gemini series.

Manned space flights demand reliable radio links with earth to track the spacecraft's path, receive telemetered scientific and operational data, and provide voice communication, for reports and commands, between the astronauts and the Mission Control Center at Houston, Tex. So long as a spacecraft is within line of sight of one of our land stations, scattered over the earth, they fill this need. But since water covers 7/10 of the globe, our Gemini program had to have three electronic support ships. Apollo flights will ultimately call for even more elaborate support.

Ships for Apollo. The coming network will employ five newly converted tracking-and-communications vessels—the Vanguard, Redstone, Mercury, Watertown, and Huntsville. Two of these will support the first, earth-orbiting manned Apollo flight; all five, the lunar mission.

Each ship is the floating equivalent of a full-fledged land station. It provides tracking, telemetry, and voice communication with the astronauts. It will have two independent links to land—by a high-frequency voice circuit, and via Comsat satellite.

For the flight to the moon, one ship will be placed in the Atlantic, east of the Florida launch site, to cover the tail end of the first phase—putting the Apollo spacecraft into a "parking orbit" around the earth. Safe insertion in orbit, and the needed orbital data, will thus be reported to Houston.

Two ships, one in the Indian Ocean and

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Sea-and-Air Armada to Aid Moon Flight

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one in the Pacific, will supplement land stations for tracking and other data at the critical time of the spacecraft's injection into its unpowered trajectory to the moon.

The other two ships, probably in the Pacific, will provide tracking and communication during the spacecraft's reentry into the earth's atmosphere. They may also be called in to retrieve the spacecraft and its crew upon splashdown in the sea—just west of Hawaii, according to present plans.

Planes to join net. Eight communications aircraft, too, will aid the lunar flight. Converted from Air Force jet transports, they will be equipped, not for tracking, but for telemetry and voice communication. Thus the astronauts can talk with the crew of the plane or, by way of it, with the Houston control center. The planes have a top speed of 600 m.p.h. and, with a full fuel load, can stay aloft about 12 hours. A huge bulb at the nose, added for Apollo use, houses a seven-foot dish-shaped, sky-scanning antenna that locks onto the spacecraft for communications.

So elaborate a communications net is required for the lunar flight, not because of the 238,000-mile distance of the moon, but because of the moon's movement around the earth. If a space flight's objective is simply to orbit the earth, we can take off whenever the launch crew is ready. But when we are to rendezvous with a target in space—whether it is an Agena or the moon—we have to time our launch in accordance with its position in orbit.

Thus, Gemini 11's successful rendezvous with an Agena in its first orbit required split-second timing of the Gemini's takeoff from the Cape Kennedy launch pad.

The moon-flight plan, instead, will allow a daily "launch window" several hours long—and have the Saturn V's third stage stop over in a parking orbit, where the space vehicle will get a final check before continuing the lunar voyage. The split-second timing is thus removed from the Cape launch pad and imposed on the instant of re-igniting the Saturn V's third stage, which will boost the spacecraft from earth orbit toward the moon.

The desired parking orbit is fixed in space. The earth rotates beneath it. So, as minor technical delays cause the moment of launch from the Cape to slip, the

Sea-and-Air Armada to Aid Moon Flight

launch azimuth of the Saturn V rocket must change continuously—say, from northeast to southeast, between the beginning and end of a three-hour launch window. For the southeast heading, precision tracking by the land station at Antigua Island may be possible. But a northeast one may put the point of insertion into orbit less than 10 degrees above Antigua's horizon, too low for reliable data. Thus an "insertion" tracking ship is needed to protect the earlier launch option.

At injection into lunar trajectory, the spacecraft's position must always be in the vicinity of the "lunar antipode"—the point on the earth's surface where the extension of a rod connecting the moon with the center of the earth would come out on the other side. Due to the earth's rotation and the moon's own movement, this point can range far and wide over the globe. On any given day its exact location varies—depending on whether the Cape takeoff has been early or late in the launch window, and on whether injection comes during the first, second, or third earth orbit. The location also will change with the launching date.

Planes can keep up. The Apollo planes will be mobile enough to chase the shifting point of injection, and assure unbroken communication at this critical phase—the entire "burn" of the re-ignited third stage and the next 20 minutes of flight, in which must come the command decision to "go" for the moon or abort the mission.

For the reentry over the Pacific, the Apollo sea-air net will be further augmented. If this maneuver cannot be conducted precisely as planned, the spacecraft may bounce back out of the atmosphere, before coming down once more at the end of a ballistic trajectory. In such an emergency case, the astronauts possibly could miss their intended splashdown point by hundreds of miles. Precise tracking will be imperative to assure their prompt and safe recovery, particularly if they come down in a bad-weather area. Hence a widespread fleet of 48 planes with advanced tracking gear will stand by to supplement the usual force of recovery aircraft.

Thus, although only a small part of it will be used at first, the sea-and-air armada required for the full Apollo program is already taking shape. ■

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New Ideas Solve the Weird Problems of SPACE WALKING

By DR. WERNHER VON BRAUN

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

When astronaut Edwin E. Aldrin Jr. breezed through a more-than-two-hour program of manual tasks outside his Gemini 12 spacecraft, in the final Gemini flight last November, he showed the feasibility of assigning practical jobs to "space walkers." His success, made possible by ingenious new aids, allayed serious doubts about the capabilities of "human-fly" astronauts that earlier trials had raised.

Space walking—or EVA, for extra-vehicular activity, as it is called in official NASA lingo—has been from the very beginning one of the major objectives of our manned space program. Its importance is obvious. Assembling large space stations and vehicles in orbit, and many other future tasks of astronauts, will depend greatly on their ability to do things outside their spacecraft. This is the reason behind U.S. space-walking trials, begun in our Gemini flights and expected to be continued in our current Apollo series.

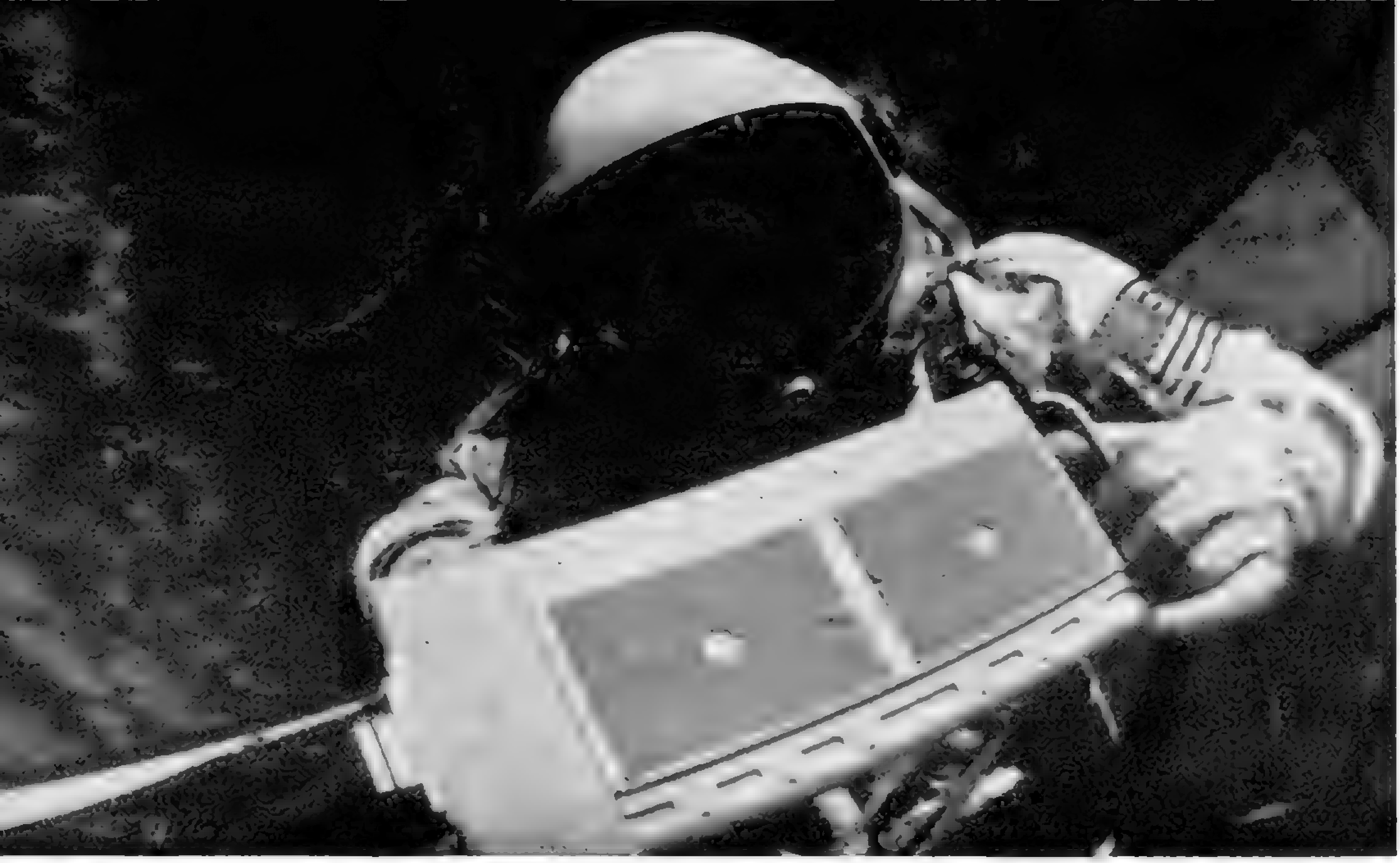
The first American EVA came in 1965 when astronaut Edward H. White II left his Gemini 4 for 22 minutes and demonstrated that, with a simple hand-held gun squirting out oxygen gas, he could stabilize himself in space and move around in any direction he wanted.

Then troubles began. It now seems that White's flawless performance led to some unwarranted overconfidence about EVA. For when Eugene A. Cernan tried to strap himself to a more sophisticated "astronaut-maneuvering unit" (AMU), a backpack carried aloft outside the *Gemini 9* capsule, he became so exhausted and overheated that his environmental-control system failed. Winded and unable to see through his fogged visor, he had to abandon the AMU experiment and return.

Subsequent EVA with Gemini 10 and 11, by Michael Collins and Richard Gordon respectively, confirmed that Cernan's experience was no isolated case but, rather, indicative of a serious and basic problem. Collins had extreme difficulty in getting a handhold on the Agena target vehicle to which his Gemini 10 was docked, and lost a camera in struggling to reach the Agena.

Gordon succeeded during his EVA in tethering Gemini 11 by a 100-foot line to an Agena. (This permitted the first artificial-gravity experiment in space, by rotating the tethered vehicles around their common center of gravity, as told in my Nov. '66 article.) Nevertheless, he became badly exhausted.

Worked like a horse. The medical rec-



Gemini 12 space walker, "Buzz" Aldrin, retrieves micrometeoroid package carried outside craft.

ords later showed that Gordon's strenuous efforts generated heat at the extraordinary rate of more than 3,000 BTU per hour, which exceeds one horsepower! Commented Dr. Robert R. Gilruth, Director of the Manned Spacecraft Center in Houston:

"We are not dealing with horses. It is not reasonable to ask nor expect a man to work at this level in space."

What was the problem, and how was it solved? Zero gravity itself could not be blamed—astronauts had spent two weightless weeks in space without tiring. Was

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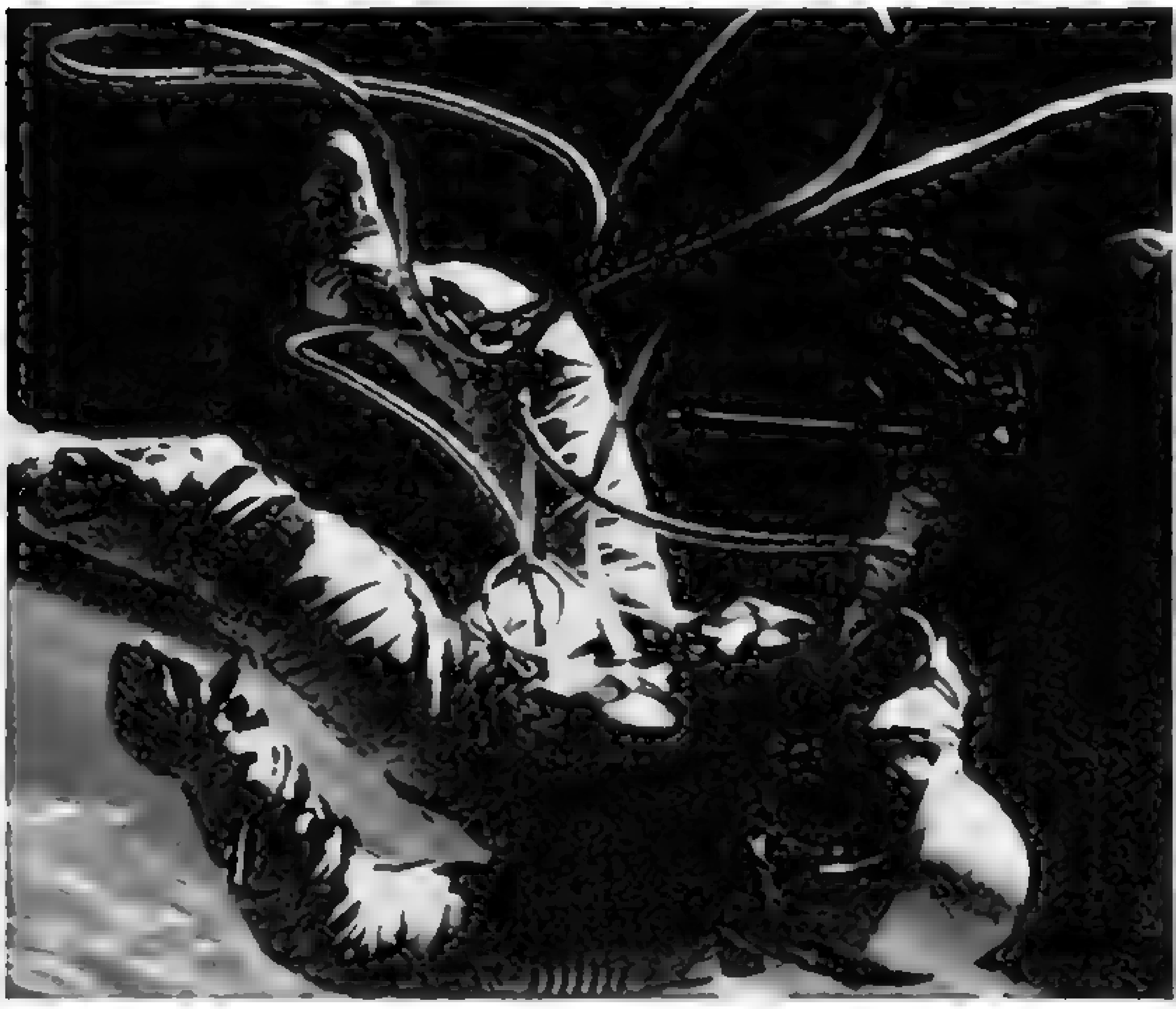
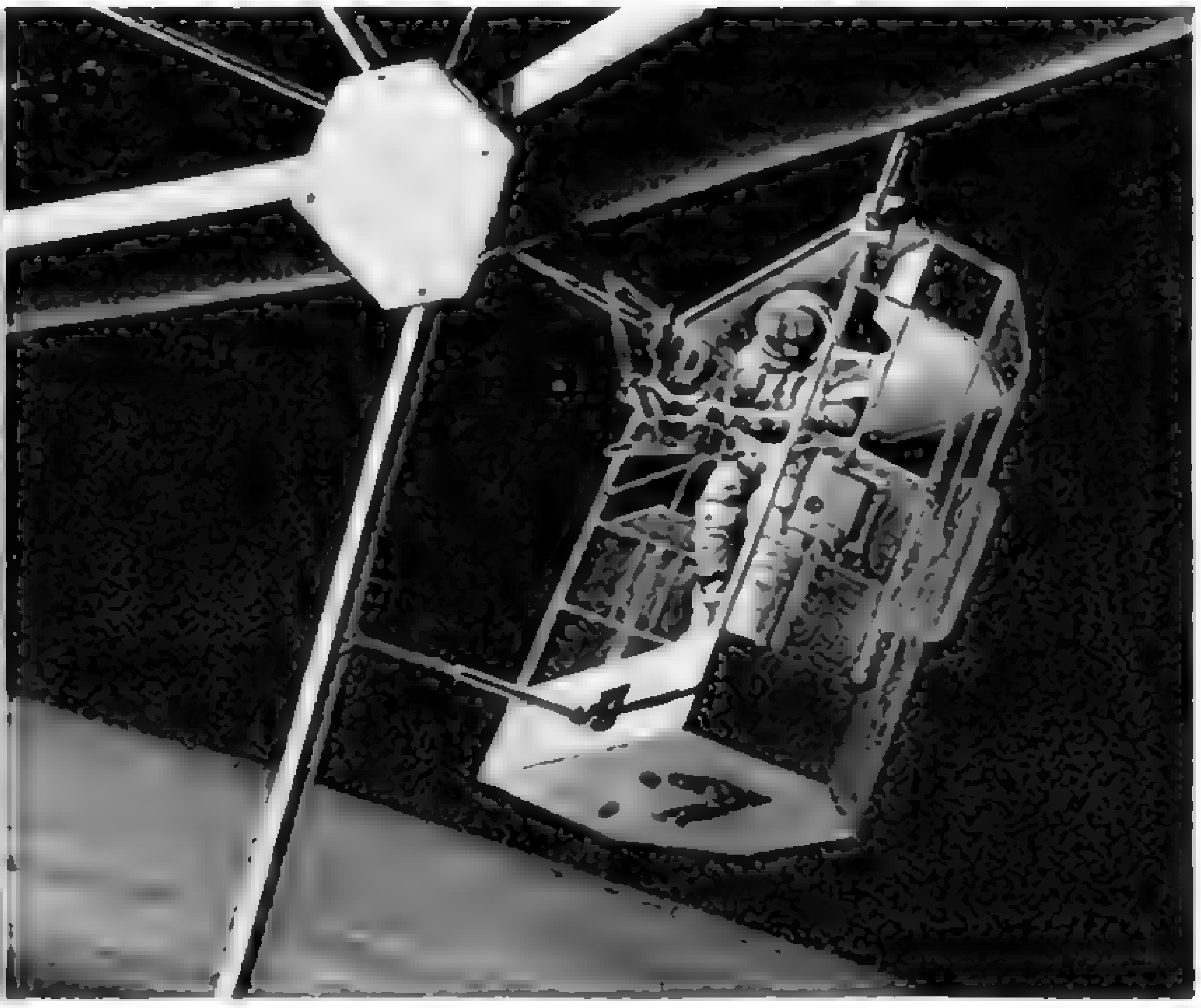


First U.S. space walker, Edward H. White II, successfully maneuvered himself on 23-foot lifeline outside Gemini 4 with hand-held gas gun. Problems of doing practical tasks awaited his successors.



Future space walkers may use aids like this "maneuverable work platform," which could be directed and attached to part of structure being worked on, to assemble large stations and vehicles in orbit.

Weird Problems of Space Walking

[Continued from page 111]

it the emotional effect of floating freely over oceans and continents? Ed White's heartbeat had given no sign that the gorgeous experience overwhelmed him at the rate of one horsepower.

The real problem. Any object freely floating in space has six "degrees of freedom." An EVA astronaut can rotate, like a pirouetting dancer, around his head-to-foot axis; or head-over-heels like a somersaulting diver; or sideways, as though he were strapped to a wagon wheel. The other three degrees of freedom are "translatory"—the astronaut can move in a straight line right-and-left, up-and-down, and fore-and-aft. And to make matters worse, the spacecraft along which the EVA astronaut is moving, or on which he is working, also has six degrees of freedom.

Moreover, in the vacuum of space, present-day space suits are a bit like strait-jackets. As you bend an arm, you fight pressure in the suit that tries to keep it straight. Add the fact that a man needs at least one hand to do useful work, and you see the real nature of the problem:

It was a full-time and exasperating job for an EVA astronaut just to stabilize himself in front of his work station, and he would have little attention and strength to spare for anything else. Ed White, whose only task was to stabilize himself at the end of a tether with his gas gun, did not run into this problem—but his successors, who tried to perform "space riggers' " functions, certainly did.

Applying the lessons. The Gemini 12 EVA test benefited from these experiences.

"Buzz" Aldrin prepared himself painstakingly. Wearing a Gemini pressure suit weighted down to neutral buoyancy, he spent a total of 12 hours underwater, maneuvering around a submerged mock-up of the spacecraft. Rehearsing his entire program of extra-vehicular tasks, he conducted time and motion studies for each job planned, and determined the number and length of needed rest periods.

Engineers of the Manned Spacecraft Center fitted him with a restraint harness that could be hooked, window-washer style, to rings attached to the spacecraft.

A happy answer to an EVA astronaut's problems in moving about turned out to be large patches of Velcro—a material, com-

Continued

bining tiny hooks and loops, that is gaining popularity as a kind of "tear-away" fastener for raincoats and the like. Push one piece of Velcro into another, and the two stick firmly together—but you can peel them apart like adhesive tape. Aldrin carried two Velcro hand pads shaped like cement trowels, and pressed them against Velcro strips previously attached along the outside of the spacecraft. This gave him support and stability as he went to his various work stations.

As the principal feature of his elaborate EVA program, a work panel on Gemini 12's rear adapter section provided 17 different tasks. They included such typical space-repair jobs as cutting cables, turning bolts with a torque wrench, and disconnecting and reconnecting snap-on pressure fittings, locking electrical plugs, and Microdot electrical connectors.

To do this work, Aldrin slipped his feet into two large stirrups, called "golden slippers" for their temperature-controlling color. Then he hooked his restraint harness to the rings on the spacecraft. In this firmly anchored position, he was able to complete his experiment program within the allowed time and without undue strain. He made his way back and forth along the craft's exterior as though he had done it many times before. All the while, his bantering exchange over the intercom system with his command pilot, Capt. James A. Lovell, evidenced that rather than being winded or exhausted, he was having a wonderful time. His "space walk," and two picture-taking stand-ups that he performed in an opened hatch, totaled a record five hours and 36 minutes of EVA.

What's ahead. Successful completion of the Gemini EVA program has paved the way for bigger things to come. Future space missions requiring EVA will include:

- Erection of large antennas in space for communications and radio astronomy.
- Assembly of large space stations, and of manned interplanetary space vehicles that are put into orbit in several prefabricated sections.
- Fueling and resupply in space.
- Inspection and repair of unmanned satellites.
- Retrieval of equipment from passive satellites.
- Space-rescue operations. PS

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How We'll Bring Spacemen

Gliding parachutes and rocket brakes, now being developed for U.S. manned spacecraft, will enable astronauts to make soft landings on the ground instead of splashing into sea

By DR. WERNHER VON BRAUN

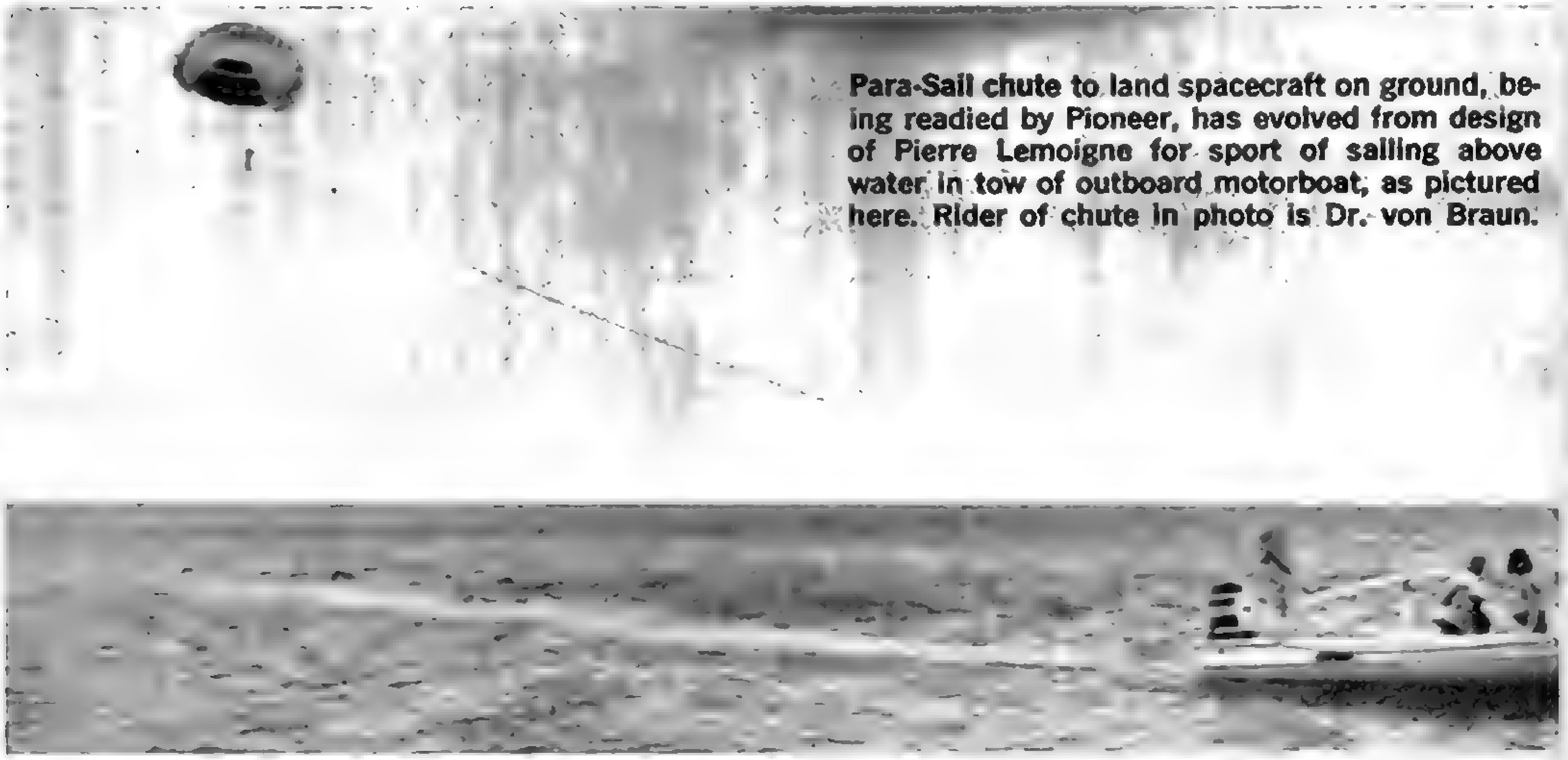
Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala., and author of the new book, *Space Frontier*

In the not-too-distant future, Apollo and other U.S. manned spacecraft will descend safely on land as well as on water. Steerable parachutes, small retrorockets, and crushable impact absorbers will enable our astronauts to come down at any number of preselected places on the ground—without giving up their ability to splash down in the ocean.

This will greatly enhance the safety and flexibility of our manned space-flight operations. As we set our aims higher, it becomes increasingly difficult to limit permissible landings to a few ocean areas. More landing options will facilitate a return from an orbit over the poles, or reentry at superorbital speed from a voyage to the moon.

The idea of land landings is, of course, not new. Ever since Yuri Gagarin returned from the world's first manned space flight, all Soviet cosmonauts have landed their craft on dry land. In contrast, all our own manned space flights have ended with a splash in the sea and recovery by ship.

Why did the two nations' landing schemes differ? Look at a world map and you will see that while the Soviet Union has plenty of land, most of her surrounding waters are cold



Para-Sail chute to land spacecraft on ground, being readied by Pioneer, has evolved from design of Pierre Lemoigne for sport of sailing above water in tow of outboard motorboat, as pictured here. Rider of chute in photo is Dr. von Braun.

own on Land

and hostile—posing great danger to a spacecraft crew unless it can be recovered within a few hours. The only friendlier bodies of water are the Black and Caspian seas and, in summer months at least, the Baltic.

The U.S. has vast land areas, too—but those inhabited sparsely enough for landings are either mountainous, or deserts with blazing summer temperatures, or prairies with winter ice and snow. However, except for rare hurricanes, weather and sea state are pleasant all year round in a vast ocean area north of the Bahamas. So the choice of water landings for the first phase of our manned space-flight program, when pinpoint landings still had to be demonstrated, was an obvious one.

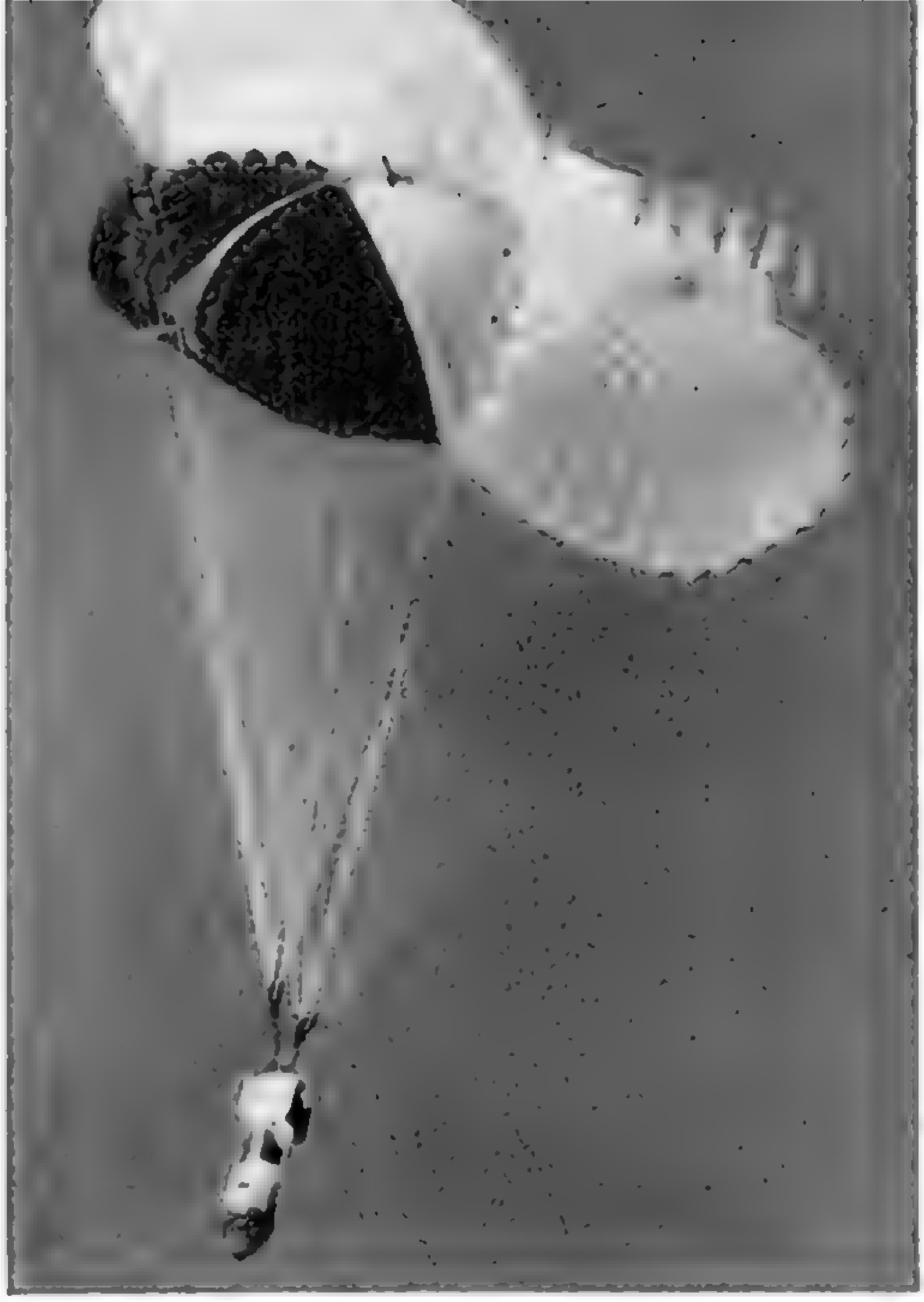
Water landings east of Cape Kennedy had another advantage. If a booster had given signs of failing, in any of our Mercury or Gemini launches, the astronauts would have immediately made an emergency landing some hundreds of miles downrange from the Cape. So our recovery ships were in an ideal standby position to aid the astronauts at splashdown—either from orbit as planned or from an abort during ascent.

USSR manned space flights have not enjoyed this advantage. Their rockets' northeasterly path, from the Soviet space center at Tyura Tam, leads across eastern Siberia. An emergency abort into those frozen wastelands could be fatal if lack of landing spots, or inclement weather, prevented immediate rescue by helicopter. This may well be one of the reasons the Soviets so far have never conducted a manned space flight during the winter.

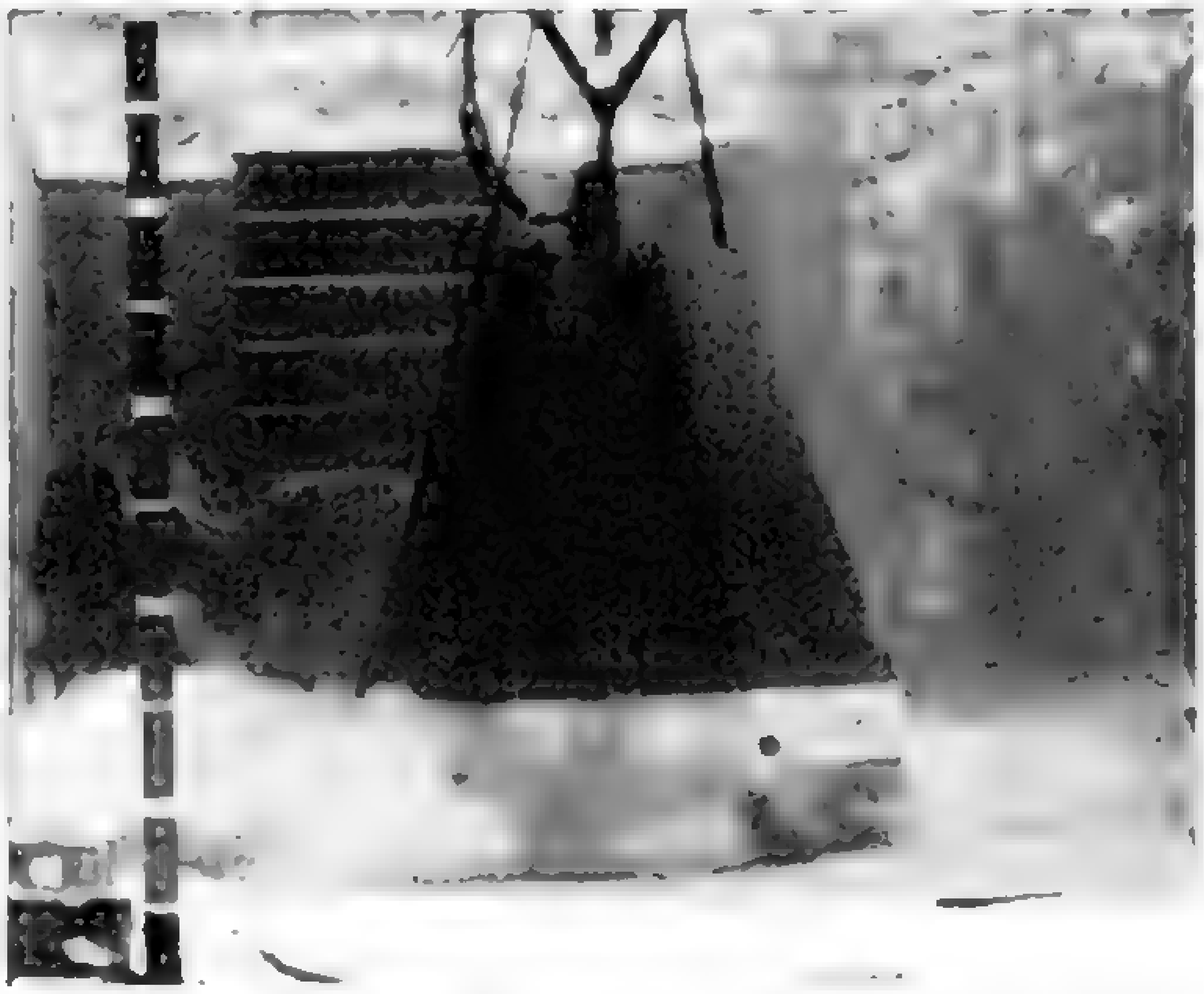
Pinpoint landings—with limitations. Since the early Mercury flights, our astronauts' landing capability has been so refined that splashing down within sight of the recovery ship has become almost routine Gemini practice. But even so, as soon as parachutes were deployed, Gemini descents were no longer controllable.

For land landings this could have been a major hazard. A spacecraft drifts with the wind. Astronauts would be unable to see the landing spot—and even if they could see it, could not evade local obstacles on the ground. Unless they were lucky enough to touch down in tight underbrush or in a swamp, the shock of impact felt in a Gemini couch would have been excessive. Had the spacecraft come down on a steep slope, it might even have rolled down the hill—a dangerous and absurd ending for a glorious space mission.

[*Continued on page 206*]



Cloverleaf parachute, developed for NASA by Northrop, lowers 2½-ton dummy capsule in ground-landing test. Controllable flaps enable chute to glide nearly two feet forward for every foot downward.



Rocket brake, triggered when probe touches earth two feet below, will ease capsule to soft landing. Photo shows solid-propellant Skirt Jet brake stopping fall of ½-ton test vehicle in Northrop trial.

Bringing Spacemen Down on Land

[*Continued from page 87*]

The Apollo Command Module has a limited capability for returning to solid earth—a land landing is acceptable only in dire emergency, like ditching an airliner in the ocean. The impact may subject the crew to up to 40 *g*'s, even on favorable terrain and despite the cushioning effects of the crushable honeycomb heat shield and the shock absorbers in which Apollo crew couches are suspended.

What's needed. To convert this emergency capability into an acceptable operational capability, the Apollo land-landing system must meet these requirements:

- The landing area will be a specified but unprepared zone, approximately 10 miles in diameter.
- The landing system must be able to operate in surface winds up to 40 feet per second (27 m.p.h.), and must permit upwind landings.
- The spacecraft must be steerable during descent, to avoid hazardous obstacles and to offset surface winds.
- The crew must be able to see the touchdown point.
- The spacecraft must not tumble or roll over on contact with the ground.
- The system should have minimum weight and bulk.
- It must be compatible with launch abort requirements.
- Since 70 percent of the globe is covered with water, the spacecraft's ability to land in the sea must not be impaired.

Best bet—a steerable chute. A kind of steerable parachute, stowable as compactly as Apollo's present triple parachute, emerges as the most promising device for a controlled glide to a ground landing.

One example is the Para-Sail, invented by Pierre Lemoigne, a French aeronautical engineer. Designed as a towable kitelike chute for sport, it turns out to perform well for spacecraft use, too.

The cloth of the Para-Sail is almost impervious to air, unlike the porous cloth of a standard parachute. Air flowing upward and rearward through slots creates a downward thrust on the lee side, making the canopy assume a glide angle with respect to the air stream. Air flow over the leading surface, producing a lift force, further increases the gliding angle. Circumferential slots—opened, closed, or inverted by

ontrol lines—enable the Para-Sail to yaw round and change the heading of its glide ath. The Pioneer Parachute Co., which in 962 acquired license rights for the Le-oigne Para-Sail, has begun a major pro-ram to apply its principle to steerable acecraft chutes.

Other efforts along similar lines include loverleaf and Glidesail types of Northrop arachutes, the Sail Wing developed by arrisch Associates, and even rotor-blade nding devices.

One major consideration in selecting the est system for the Apollo spacecraft will e whether it offers the safety feature of dundancy, as do the three parachutes of pollo's present nonsteerable landing sys-m. Should one of these parachutes fail, water landing can still be made safely ith the other two.

If the need to see the touchdown point to be met by looking out the space-aft's windows, the crew will have to ride own in a sitting position, which will re-uire changing the way the Apollo Com-and Module is suspended from chutes. he present way, which lands the astro-auts lying on their backs, would call for direct viewing via a television camera nd a screen on the instrument panel.

Unaided, even a steerable parachute ould have to be impracticably large and eavy to bring down a manned spacecraft a land as gently as we aim to do. The resent Apollo spacecraft splashes down at 3 feet per second (19 m.p.h.) with all ree parachutes deployed, and at a still-lerable 34 feet per second (23 m.p.h.) on vo chutes. But we plan a much slower escent to a land landing, at something ke eight feet per second (5½ m.p.h.).

A rocket brake. A likely answer is to ow the descent just before impact with an ray of small downward-firing rockets, ig-ited a few feet above the ground. The ockets may be embedded in the Command lodule and fired through the periphery the heat shield—or, alternatively, placed the parachute risers.

The remaining shock of impact will be ushioned either by leg-type landing gear, by crushable material inserted between e heat shield and the interior structure of e spacecraft. Supports extended shortly efore touchdown will prevent the capsule om tumbling after landing. PS

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Rocketin

To get back safely from an aborted mission, our Apollo astronauts will fall or orbit away from trouble between the earth and the moon

By DR. WERNHER VON BRAUN

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

A manned voyage to the moon is a pioneering project of unprecedented dimensions—in the distance it will take man from the earth, in the rocket power it will require, and in the complexity of its techniques and space maneuvers.

Many things can go wrong, during preparations and on the way. Those mishaps and equipment failures must not be as catastrophic as the flash fire in which three brave and dedicated astronauts lost their lives two months ago—a disaster during a pad-checkout test of the first manned Apollo spacecraft, after an uninterrupted string of successful ground tests and flights with all our Mercury and Gemini craft. A thorough and critical reappraisal of fire hazards and ways to reduce them, under way at this writing, should prevent a recurrence of such a tragedy.

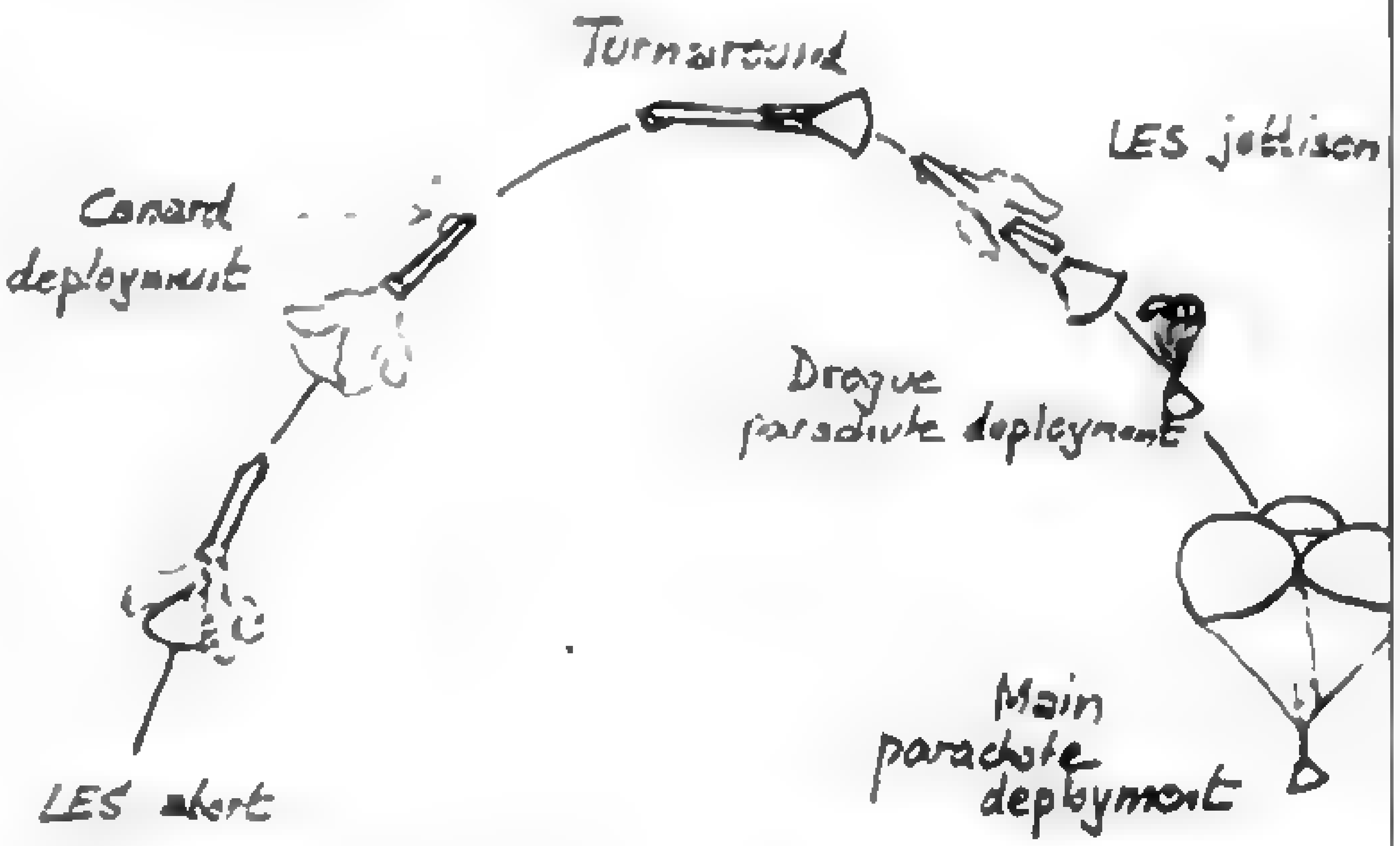
But there are other potentially hazardous situations, requiring equally serious attention, that may confront the astronauts after an actual moon voyage begins.

From the outset, a ground rule of our Apollo program has been that, even if the aim of a lunar landing has to be abandoned during any flight, chances for the crew's safe return to earth must remain high.

Hence our moon-voyage plans provide a succession of appropriate "abort" procedures for getting out of critical situations during launching, on the way to the moon, and later. The crew's best course of emergency action will change continuously, as rocket stages and spacecraft modules are successively discarded.

In case of a false start. Through the entire 140-second burn of Saturn V's first stage, the Command Module carrying the three astronauts can be hurled a safe distance away from a faltering launch rocket and parachuted into the sea.

The way back to earth is via LES, the Launch Escape System—a solid-propellant



rocket mounted on a tower atop the spacecraft, and triggered automatically or by the crew, depending on the kind of emergency. As it fires, the Command Module separates from the Service Module. What happens next is shown in my sketch above:

At the high-g escape rocket's burnout, "canard" fins at the tip of the tower are deployed, and aerodynamic forces on them swing the tower into the wake of the Command Module. At 25,000-foot altitude the tower is jettisoned, and drogue parachutes unfurl. At 12,000 feet the main chutes open and lower the Command Module for a safe splash. From an abort toward the end of the first-stage burn, the astronauts will land in the ocean about 400 nautical miles downrange from Cape Kennedy.

If all goes well during the first-stage burn, the LES will be jettisoned soon after Saturn V's second stage takes over.

Then, for the early part of the second

Out of Emergencies

stage's six-minute burn, the available abort procedure is "sub-orbital free fall":

The combined Command and Service Module (CSM) separates from the launch vehicle and a 10-second burn of the Service Module engine adds distance. Then the Command Module, separating from the Service Module, turns around and reenters the denser atmosphere with its blunt heat shield forward. A free-fall abort as late as feasible, three minutes after ignition of the second stage, would land the crew in the Atlantic about 3,200 nautical miles downrange of the Cape and just short of the African coast. This abort procedure can be modified, by a second Service Module burn, to maneuver the splashdown point closer to a recovery ship and thus shorten the waiting time for the ship's arrival.

Uphill into orbit. Should trouble strike after the second-stage burn is half through, "uphill" abort into parking orbit is the answer. The balky second stage will be dropped and the third stage fired up. It will enable the crew to reach a low orbit where they can stay, even for days, until the time rolls around for a Gemini-style reentry and a precision splashdown near a recovery ship.

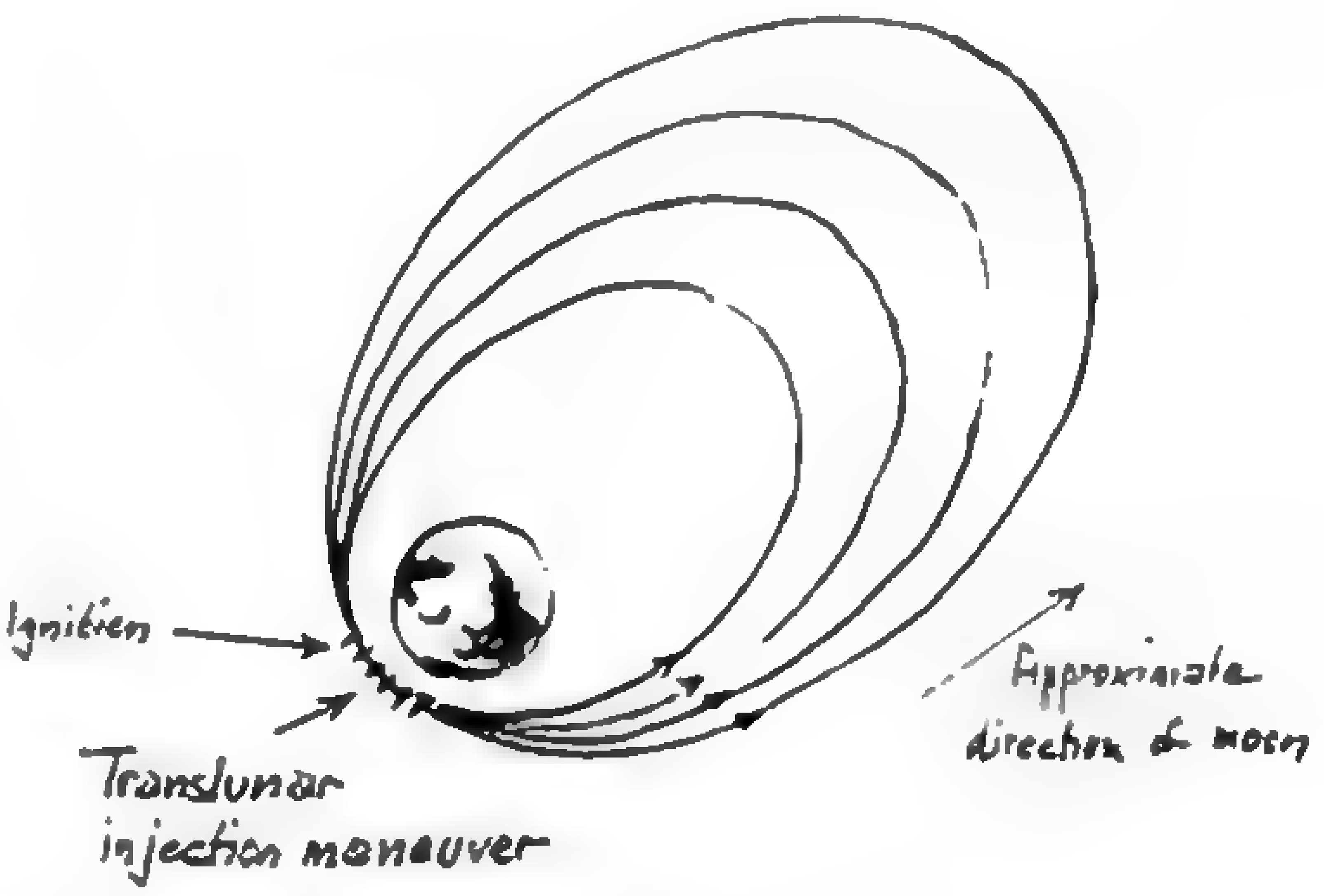
The astronauts would use the Service Module propulsion system, whose fuel reserves remain untapped, to de-orbit back into the atmosphere. In the unlikely case that it failed, they could de-orbit with the Saturn's third stage. Or, after docking the Command Module to the Lunar Module and extracting the latter from the Saturn, they could fire the LM's descent engine.

After a normal ascent into the planned Apollo parking orbit, the astronauts can descend the same way, if they discover that some faulty subsystem makes it impossible to continue the voyage to the moon.

Translunar injection. The next power maneuver of the lunar-flight plan is translunar injection—the second burn of Saturn V's third stage, to drive the spacecraft from its earth-circling parking orbit into a trajectory toward the moon. Should the third stage fail during this power maneuver, the astronauts would turn off its engine, and separate their spacecraft from the balky rocket stage. Then they would use the Service Module engine to drive themselves back into the atmosphere.

My sketch below shows the family of gradually widening elliptical orbits in which they could wind up, if the 340-second power maneuver for translunar injection ended too soon. If a premature cutoff occurs early, the period of revolution in elliptical orbit will be on the order of a few hours. But if it happens shortly before we reach the speed that would take us to the moon, the period of revolution may be several hundred hours. This opens a new aspect of possible abort situations:

Are we in a hurry to get back to earth—for instance, because the spacecraft's life-support system or its electric-power equip-



ment is acting up? Or is our predicament such that we must try to return with a minimum of fuel—perhaps because we have discovered a fuel leak? Is it safer to splash down in good weather and daylight near a recovery ship, even if this takes a little longer? Or is our emergency so pressing that we'll accept less-desirable conditions to get down sooner?

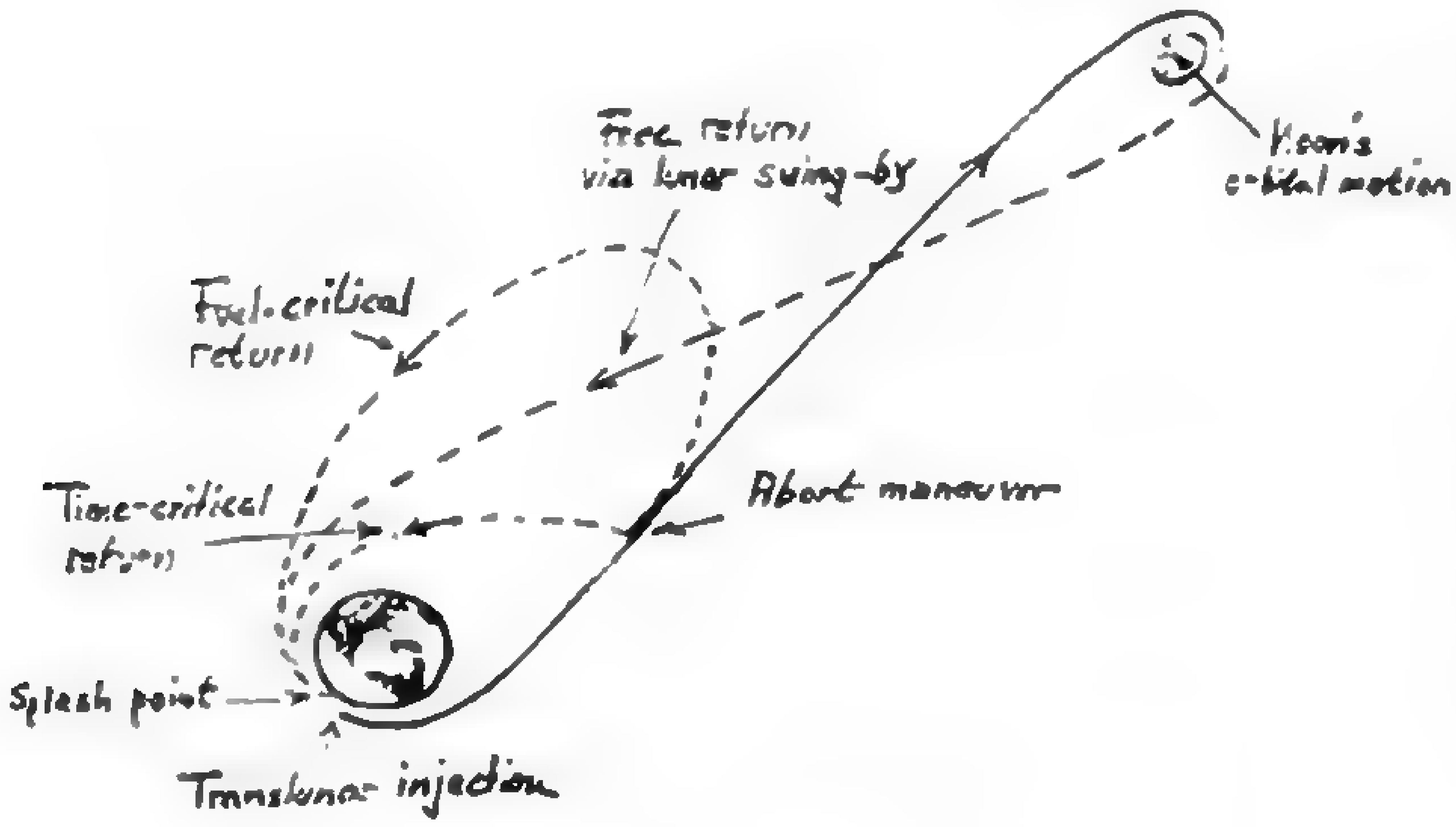
We have a wide choice, now that we are in deep space. The flight director, in consultation with the command pilot, must weigh all the factors to select the best abort procedure for a particular situation. My sketch on the following page shows the principal difference between "time-critical"

and "fuel-critical" abort maneuvers on this leg of the flight.

And this choice between fast and fuel-saving returns is still open to us, in case of trouble during the three-day unpowered coast to the moon that follows translunar injection.

"Snapping the whip" around moon. As we get closer to the moon, however, another abort option presents itself: Why not just keep going, and let the moon's gravity swing the spacecraft around and throw it back to earth? All early-Apollo flight plans are carefully designed to offer this "free-return" feature.

Free return requires one or more minor course corrections to bring the spacecraft precisely into an acceptable atmospheric-reentry corridor, and to time the arrival so as



to reach a preselected landing site on the rotating earth. But there's plenty of power left for these final corrections, since no fuel has been expended to de-boost the craft into a lunar orbit and get it out again. And if our trouble deprives us of a lunar landing, a free-return swing around the moon still gives us at least a close-up look at our heavenly target.

De-boost into lunar orbit. Next in the flight plan comes the lunar-orbit injection maneuver. Using the Service Module engine as a brake, the astronauts can slow down enough to let the moon capture their spacecraft in a circumlunar orbit. If the engine failed to start, their lives would not be in serious danger. Due to the free-return feature, they'd simply sweep around the moon and be on their way home.

Premature cutoff or overburn could create some rather hairy situations for them—but, even here, carefully planned emergency procedures will give them high assurance of safe return from a mission in trouble.

If the engine started and then stopped prematurely, one possible result could be an unstable elliptical orbit around the moon, which would ultimately hurl the spacecraft out of both the moon's and the earth's gravitational fields. A premature cutoff somewhat later could put the spacecraft into an elliptical orbit with the unpleasant feature that its lowest point is below the moon's surface! Similar "impact ellipses" would result from an overburn that slowed the spacecraft down to a speed below the desired capture speed.

All these cases call for quick action by the crew. The spacecraft must be turned to an attitude in which its restarted Service Module engine will promptly restore the required direction and speed of motion. Or if that engine balks, the Lunar Module descent engine must be swiftly pressed into service to avert a crash.

Lunar landing and reascent. Almost the only element in the entire lunar-flight plan where the crew's survival depends on flawless operation of nearly all systems is the LM, the Lunar Module. In it, two of the three astronauts will descend from lunar orbit to the moon's surface, and return to the Command and Service Module left circling in orbit. In the unlikely event that they are forced to abandon the landing attempt a few hundred feet above the lunar surface, they must come back at once to the CSM.

Descent of the LM to the lunar surface and return to the CSM is possible only if all vital parts of the LM work well. This is an accepted risk in the Apollo program. Since the CSM cannot land on the moon, all abort procedures for the landing party must aim at a successful rendezvous with the CSM. It is the only way to get home.

Returning to earth. After the lunar landing party has reboarded the Command Module, the CSM is on its own. Gone is the backup for a balky Service Module that the LM propulsion system provided before. For the return to earth, therefore, abort procedures no longer exist—but the planned flight back has just the same purpose, safe return of the crew. The only difference is that a normal return ends a completely successful mission.

ABCs of Keeping Your Car in Tune

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Are You Safe from Electronic Snoopers?

A Space Man's Look at Antarctica

Seeking lessons for lunar and planetary missions, the author and other NASA leaders pay a visit to the South Pole, and make a tour of U.S. research bases on a frozen continent

By DR. WERNHER VON BRAUN
Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

As a stand-in for Mar[s] would this site serv[e] Wright Dry Valley, one [of] several accessible by he[li]copter in Royal Socie[ty] Range, is inspected by Dr[s] Gilruth, Faget, and vo[n] Braun. Because life is ju[st] beginning to find a footho[ld] in these "dry valleys" le[ft] by receding glaciers, they'[re] being studied as a possib[le] proving ground for instru[ments] to detect traces [of] bacteria and other lo[w] forms of life on Mars.

At South Pole, space men march around marker—and, with broad grins, claim "orbiting" earth in less than five seconds. Facing camera are Dr. Gilruth and (behind him) Dr. von Braun.

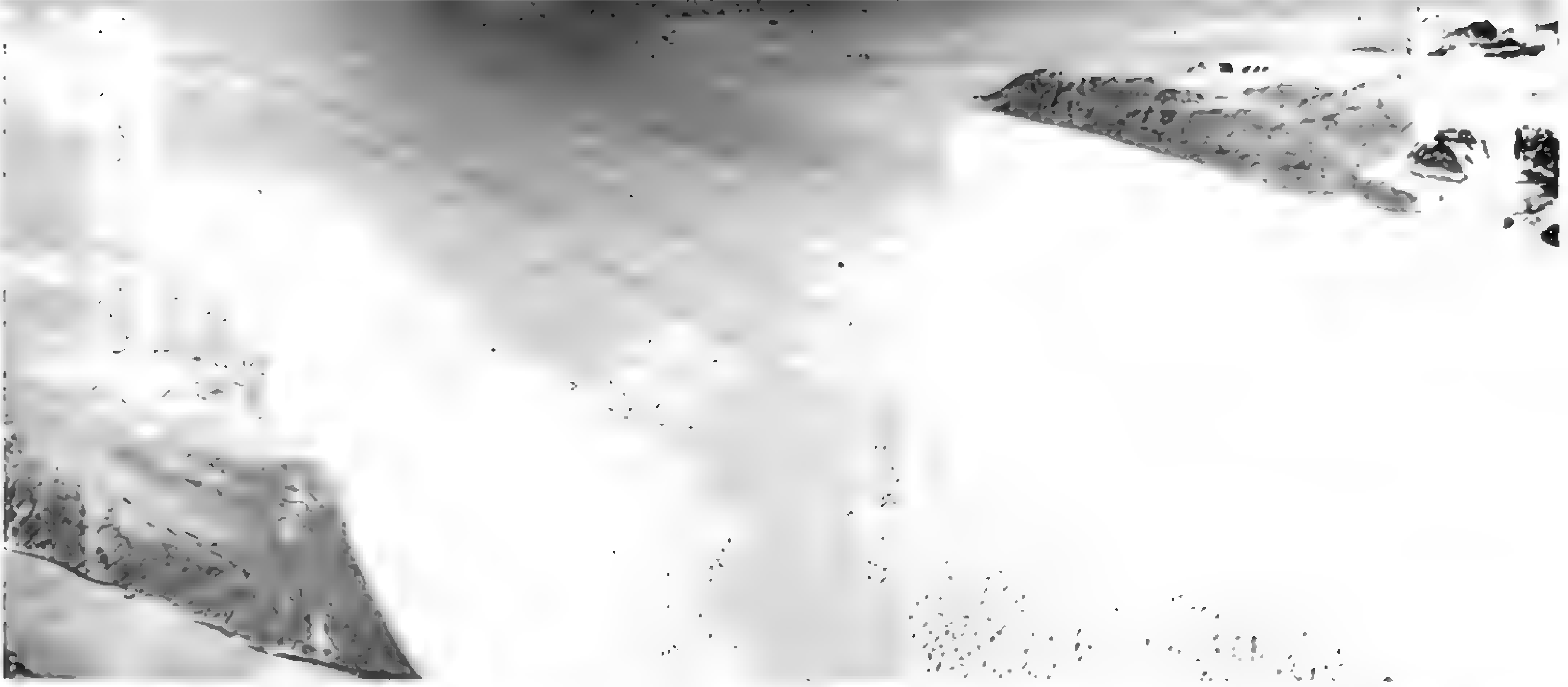
It may well be smart to test lunar vehicles or surface drills in Antarctica befor taking them to the moon. It may be a good idea to try out automated life-detecting equipment in the Antarctic's unique dry valleys before it's sent to Mars. And, more important in my view, our Antarctic activities offer lessons for the whole procedure of space exploration.

Those are impressions of a week I spent in Antarctica last January, as a member of a NASA party that included Dr. Robert R. Gilruth, Director of the Manned Spacecraft Center in Houston; Dr. Maxime Faget, Houston's Director of Engineering and Development; and Dr. Ernst Stuhlinger, head of the Research Project Laboratory at the Marshall Space Flight Center.

We went down to see what we could learn for our space program from man's activities at his last real frontier on earth. True, Antarctica has an atmosphere, while

Continued

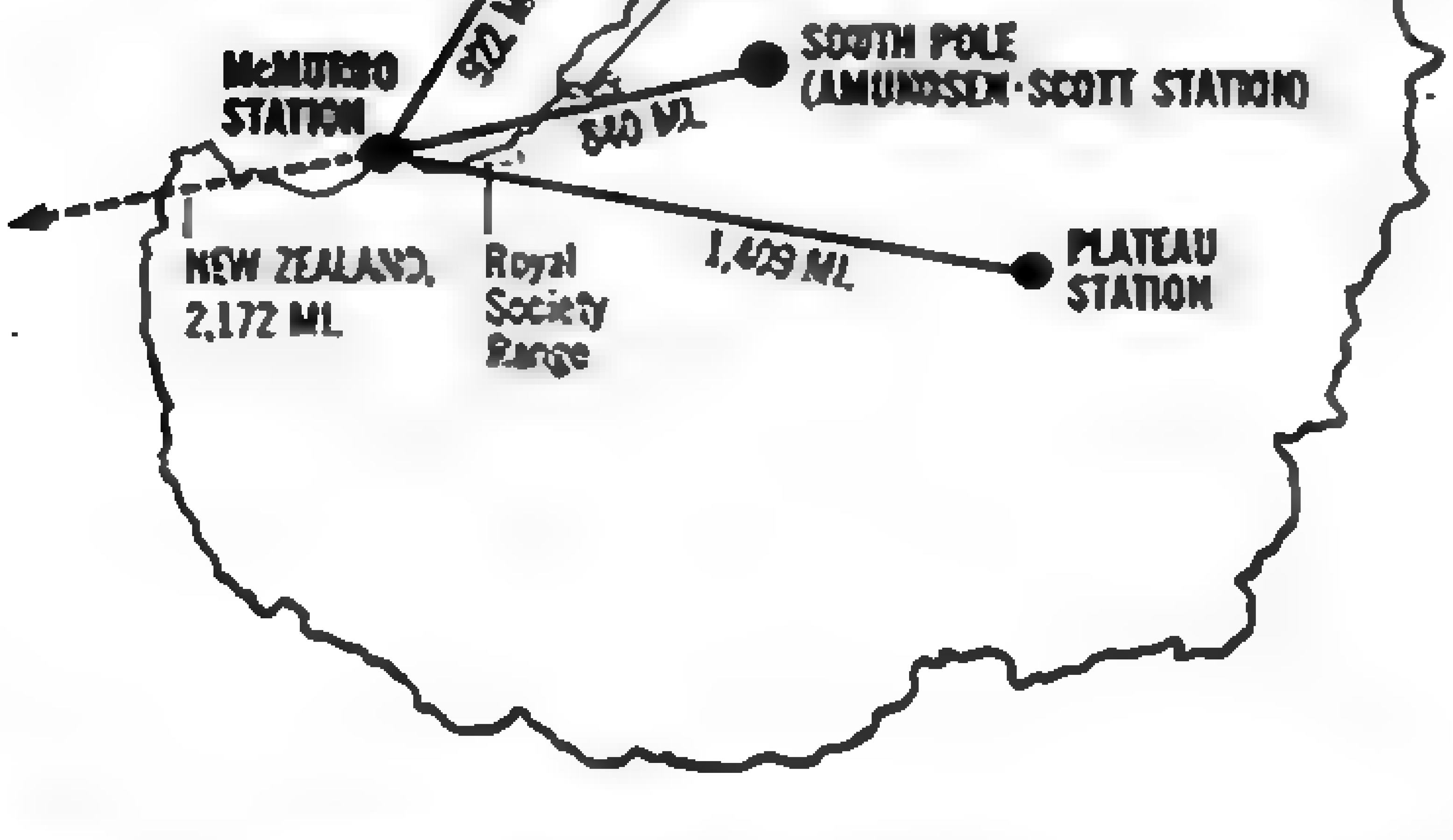
Dr. von Braun meets the penguins—and gets emphatically told by one to mind where he's walking—at a rookery on Cape Royds near the McMurdo base.



Beardmore Glacier—probably the largest in world, 45 miles wide and 250 miles long—is viewed from air. Planes, helicopters, and tractors ease Antarctic travel today, though dog sleds still find use.

the moon has none. A parka in lieu of a space suit wouldn't do on the moon. And the moon doesn't expose astronauts to Antarctic dangers of blizzards and whiteouts. But the two scenes have much in common:

In both programs, the major objective is scientific research. Success hangs on a long, complex, costly, vulnerable line of logistics. Rewards, besides scientific knowledge, extend to all aspects of conducting exploration. One of the most valuable will be a yearly crop of men imbued with the spirit of exploring, seasoned by the hardship of the environment, and experienced in the



Map of Antarctica shows some of the U.S. bases visited by space men. McMurdo Station tracks satellites, and Byrd Station collects data from them.

teamwork that all major efforts require today. Finally, both in Antarctica and space, America is not alone in seeking to explore a new frontier.

Where space men went. Using McMurdo Station, the American "port of entry" and key supply point, as our staging base, we visited New Zealand's nearby Scott Base and five more U.S. stations in Antarctica.

We spent a night at Amundsen-Scott Station, right on the geographic South Pole—and couldn't resist the temptation to go our astronauts one better by walking around the earth in less than five seconds per "orbit." We stayed overnight at Byrd Station, a veritable city of trailer-type accommodations completely buried under ice and snow. We visited pioneers' huts built of two-by-fours more than 50 years ago.

We tried every means of Antarctic travel—huge four-engine Lockheed LC-130 turboprops, helicopters, Snow-Cats, motor toboggans, dog sleds. We flew across the vast glittering expanse of central Antarctic ice fields and landed at Plateau Station, at an elevation of over 12,000 feet. We were overwhelmed by the grandeur of such sights as the enormous Beardmore Glacier and the Royal Society Range.

And our trip brought us face to face with everyday realities of our great national Antarctic program—conducted, like our space program, by a breed of wonderful people in a starkly beautiful but unforgiving environment. What did we learn?

Lessons came in bits and pieces, from the whole range of activities we saw. All

[*Continued on page 200*]

A Space Man's Look at Antarctica

[*Continued from page 116*]

will save our space program time, money, and frustrations. Here are samples, not to be considered as final conclusions but as food for thought and further study:

Who's to give orders. Research at a typical U.S. Antarctic station may be in fields as varied as radio-wave propagation, upper-atmosphere studies, glaciology, microbiology, and the breeding habits of the skua, a gull-like bird of prey. The scientists' activities and needs are coordinated by a Station Scientific Leader, who is responsible to the National Science Foundation's Office of Antarctic Programs.

But the scientists depend for their well-being, and their very survival in an emergency, on the U.S. Navy—which builds, maintains, and supplies the Antarctic stations, and provides communications and air transportation. So each major station has an Officer-in-Charge—representing the Commander, Naval Support Force, Antarctica —who sees to the safety and support of all personnel. In an emergency, jointly determined by him and the Station Scientific Leader, he takes full command.

Would the problem be very different in a space station for astronomical research, we wondered, if the life-support system started acting up? Maybe a future space station, too, should have both a Station Scientific Leader, and an Officer-in-Charge —an astronaut with an aviation and manned-space-flight background.

Fall-back camps. Fire is considered the greatest hazard for an Antarctic station. Besides a fire-warning system and extinguishers, each station has a "fall-back" camp a few thousand feet or so away. It provides emergency shelter, food, and medical supplies for all the staff, and has its own radio. If fire destroyed the main station the men could thus ride out even a two-week blizzard, until a rescue party arrived. Wouldn't this be a good idea on the moon, too? And how about a "fall-back" camp for a manned space station?

Prefabricated stations. Unlike early huts nailed together at the site, the most modern ones we saw were completely built and equipped in the U.S. Plumbing and wiring were installed and checked, and even the pinup girls seemed to have been pasted on living-room walls, before they were flown to their locations. Preparing your station as completely as possible before you ship it out into the cold seemed good for space, too.

Surface vehicles. Whether or not we try out moon vehicles in Antarctica, we saw lessons for their design, in down-to-earth experience with a variety of land vehicles used there—Tucker Snow-Cats for long treks, three-wheeled Gnats for short hauls around McMurdo and Scott bases, small motor-toboggans and larger Thiokol Trackmasters on the plateau:

Riders in bulky clothes must be able to climb in and out freely. Vehicles must be easy to load and unload. Major parts—engines, tracks—should be interchangeable in the field by men in Arctic gear. Vehicles must be towable. Most important, different purposes demand different vehicles.

Antarctica offered other hints for our space program—in patterns for research, in choosing men and sustaining morale. And already in progress there are some actual space activities.

Space work in Antarctica. Since 1965, a Doppler tracking station at McMurdo has recorded more than 700 satellite passes monthly. Byrd Station regularly collects data from some U.S. and Canadian satellites. Those in polar and near-polar orbits cross the Antarctic at every circuit. And data tell of the interesting "hole" in the Van Allen Radiation Belt, where the earth's magnetic-field lines dip down to converge at the South Magnetic Pole.

Less than 100 miles from McMurdo in the Royal Society Range are Antarctica's "dry valleys," formerly covered by glaciers. Due to reduced snowfall in recent centuries, the glaciers have receded, and exposed virgin expanses of rock and pebble-strewn soil. Life, in the form of organisms carried by the wind and bird droppings, is just finding a foothold. Here is an ideal setting to study detection of traces of life on other planets.

NASA's Jet Propulsion Laboratory in Pasadena has a brilliant microbiologist doing field work in the dry valleys, in preparation for the Voyager spacecraft project. Ultimately, maybe Martian-life-detecting instruments should be tested in the dry valleys, where men can go in and compare the instruments' findings with the real facts. And the future may well bring other uses of Antarctica as a proving ground for space equipment. PS

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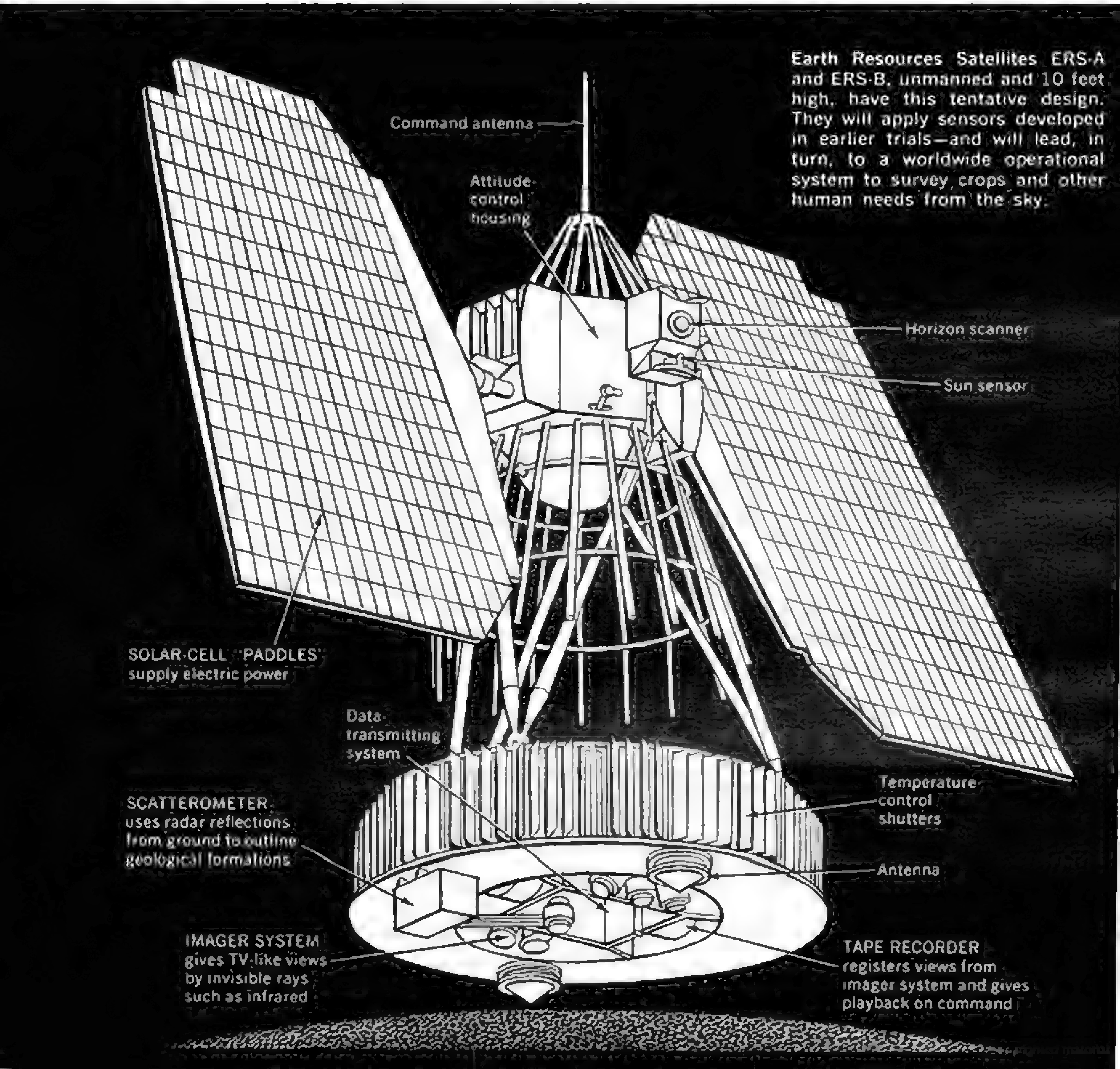
Eyes in the Sky Wil

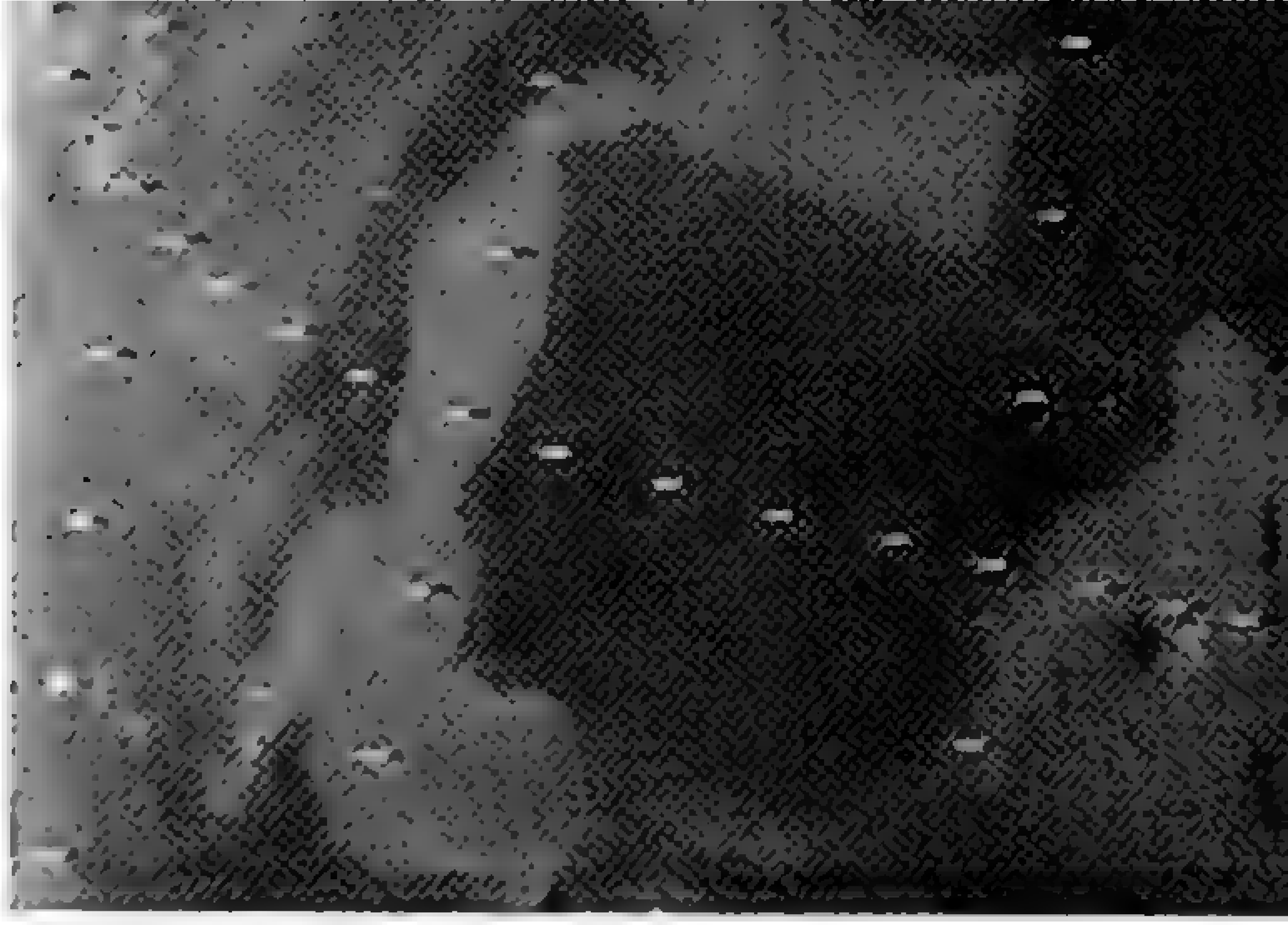
By viewing our globe with cameras, radar, and TV-like sensors, coming Earth Resources Satellites will bring latest reports of growing crops, cattle, fish, timber, and minerals

By DR. WERNHER VON BRAUN
Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.



Earth Resources Satellites ERS-A and ERS-B, unmanned and 10 feet high, have this tentative design. They will apply sensors developed in earlier trials—and will lead, in turn, to a worldwide operational system to survey crops and other human needs from the sky.

elp Feed World



View of Spain from Nimbus II satellite gives a sample of what orbiting sensors can reveal. Banded pattern of sea west of Spain, in infrared picture, charts water temperatures—an aid in locating fish.

As we are setting out to explore the moon and the planets, we have discovered that the most interesting object to study from space is our own earth. Scheduled to begin in late 1969 or early 1970, three manned flights of the Apollo Applications Program will scan the globe with tools originally conceived to explore other worlds—sophisticated cameras, spacecraft TV outfits, "side-looking" radars, other remote sensors.

Soon after, NASA plans to launch two unmanned Earth Resources Satellites, as the next step toward an operational system for a constant, worldwide survey of earth resources from orbit.

The term "earth resources" embraces everything man needs to survive on this planet. It includes food crops, cotton, fresh water, timber, oil, mineral deposits, fish, wildlife, cattle and sheep. To gauge these resources, we must continuously observe the land on which crops and cattle grow, and the sea in which the fish live. Suddenly this is becoming urgent.

Population experts foresee that in the year 2000, just 33 years hence, our earth will have to feed twice as many people as today. Unless we make the most of the time left to find how best to use our limited earth resources, the vast majority of mankind may soon be locked in a struggle for sheer survival.

Satellites to the rescue. Earth Resources Satellites may well change the course of history. They may prevent wars born of starvation, by helping to provide food for the two-thirds of the world's population now inadequately fed. They could lift underdeveloped nations from poverty by locating unknown deposits of oil or minerals.

That's why NASA, encouraged by the Departments of Interior, Agriculture, and State, has embarked on a program to develop the technology for future Earth Resources Satellites.

The fabulous earth pictures taken by Gemini astronauts with a hand-held Hasselblad camera gave the idea its biggest boost. Our meteorological satellite Nimbus II demonstrated another kind of sensor—an infrared imaging system that showed not only continental outlines but also water masses of various temperatures. Such information, together with measurements of plankton content (indicated by a greenish hue of the water) and salinity (determined by a satellite-borne polarimeter), may one day locate schools of fish.

Now the Earth Resources Satellite program has progressed to some tangible hardware of its own.

Planes test new sensors. To gauge the usefulness of a variety of prospective instruments for Earth Resources Satellites, the Manned Spacecraft Center in Houston is currently flying them in two specially equipped aircraft, a Convair 240A and a Lockheed P3A.

With photographic, radar, infrared, ultraviolet, and microwave sensors, the aircraft get images of terrain that are especially suited to the geologist, hydrologist, geographer, oceanographer, agriculturist, or forester. Comparing them with the "ground truth," found by ground inspection of the areas flown over, has shown how to interpret the aerial images.

What do these "earth sensors" look like, and do? Here are some examples:

- A multi-spectral camera photographs the same terrain on two or more color films at once, using a different filter with each film. The respective films' tonal differences tell the quality of the soil, and identify the particular crop that is growing on it.

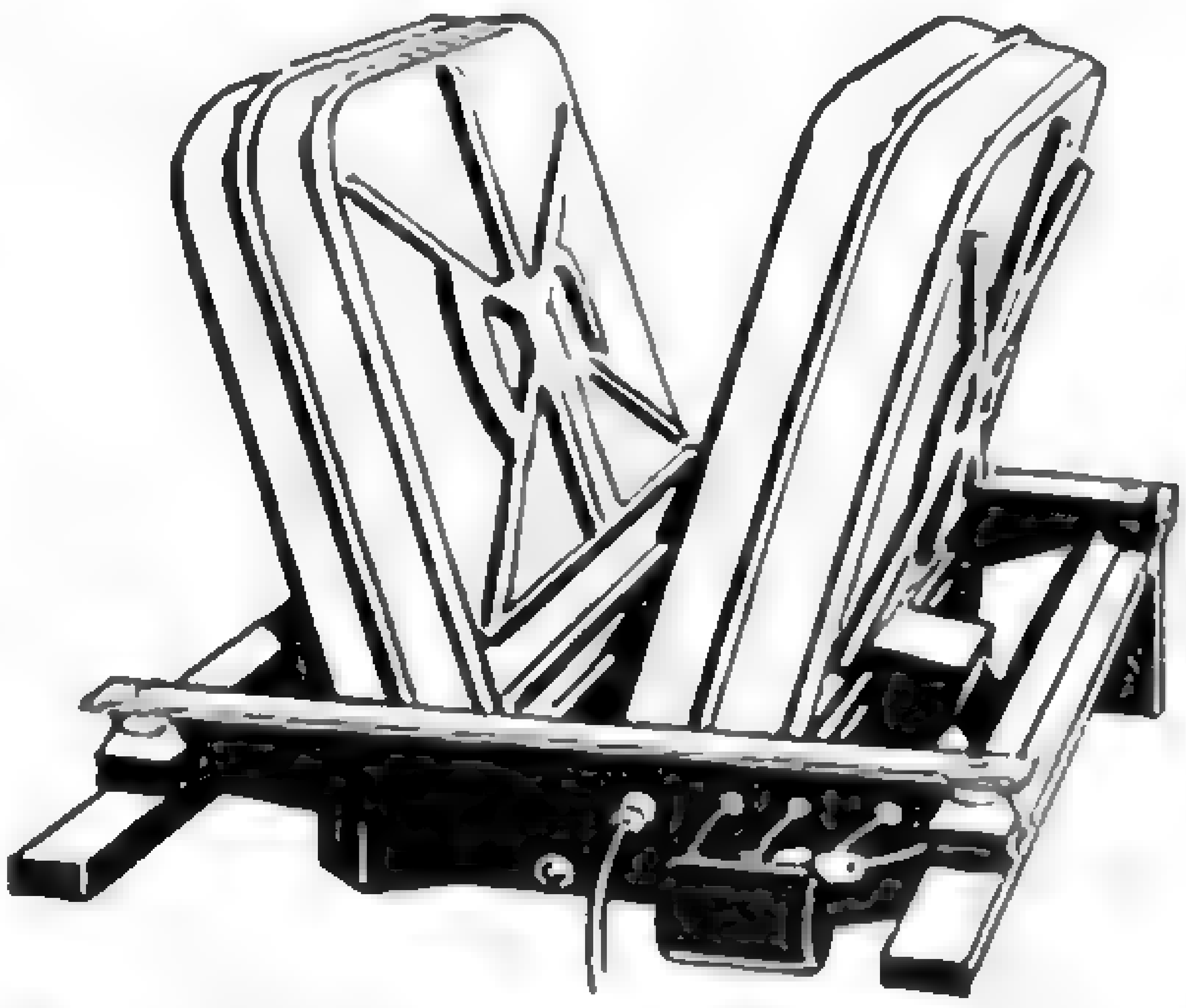
Continued

• An imager, especially useful in the infrared region of the spectrum, gives TV-like images. These go to a tape recorder, along with code signals to identify the areas viewed. On command from earth, tapes are "dumped" by radio to a ground data-collecting station.

• A scatterometer, a radar device, determines reflection characteristics of the ground. For instance, it can show the outlines of the rocky backbone of a mountain range overlaid by soft soil or sand. This is of great importance for geology and ore prospecting.

Already Houston's work has resulted in selecting a number of particularly promising sensors, besides producing a technique of data cataloguing and distribution that offers a kind of prototype for future satellite-borne systems.

Tests in orbit. Next, the sensors must prove their worth at orbital altitudes, in three of the manned Apollo Applications flights. A multispectral camera will ride the first flight; the others will carry a whole array of additional sensors.



Multi-spectral camera makes photos on two films through different filters. Tonal differences between films identify crops and tell soil quality. Instrument shown was developed by Mark Systems, Inc., Santa Clara, Calif.

Each of these flights will last between one and two months, much less than the useful life of future operational Earth Resources Satellites. But the Saturn-boosted Apollo spacecraft's large payload capability will permit a full complement of instruments. And trained scientists aboard will be able to detect from orbit any unforeseen clues to natural or artificial phenomena on earth, which might open exciting new possibilities.

The Earth Resources Satellites that follow, ERS-A and ERS-B, will use whatever sensors emerge from all the trials. Probably these small unmanned satellites will outwardly resemble Nimbus. While lacking the advantage of sophisticated adjustments by an astronaut aboard, they will be less expensive and longer-lived than the preceding manned flights. They may even have some operational usefulness—though they really are only laying the groundwork for an operational worldwide system.

That "ultimate" system might employ a combination of low polar and high synchronous satellites—whether manned or unmanned, it is still too early to say. It is bound to be subject to refinement, improvement, and expansion for many years.

Possibilities of such a system kindle the imagination. Airplane tests have shown that the new sensors will tell a wheat field from an oat field, a rice paddy from a corn patch, soy beans from cotton. Photos and sensor images clearly show if crops are thriving, or expectation is poor. Too much salinity in soil, inadequate soil-moisture control, lack or wrong use of fertilizer, hail damage, drought effects—all come to light at once, to the eye in the sky.

The same instruments reveal how the world's population is spreading. Growth of cities, and road construction, tell the story. Determining where the food is and where the eaters are provides the two factors of supply and demand that we must know if we want to see that nobody goes hungry.

Added uses. The list of uses of an Earth Satellite System is expanding. It could warn of volcanic eruptions, earthquakes, tidal waves. It could help discover underground streams to irrigate parched fields nearby. It could chart areas of pest-infested timber, to guide rangers in spraying from the air. It could provide a simple tool to update all the world's maps.

Finally, an integrated Earth Resources system is by no means limited to direct observations from orbit. Its satellites may also collect information by radio from unmanned probes on land and sea—and promptly relay those messages, too, to a central data-collecting station.

Today it looks as if man can no longer exploit natural resources arbitrarily. They are not inexhaustible. The time to act is now—and our Earth Resources program pioneers the way. PS

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... WE'LL LAND ON THE MOON

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How We'll Land on the Moon

An expert's preview takes you on the Flight of the Bug—90 miles down to a lunar landing and back

By DR. WERNHER VON BRAUN

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

ILLUSTRATIONS BY BOB MCCALL

Bug's flight begins when, with two astronauts aboard, it casts off from Command and Service Module (upper craft) to descend 90 miles to a rocket-braked soft landing on surface of moon.

The climax of our Apollo program will be the descent to the surface of the moon of the Lunar Module, popularly known as the Bug.

From photos made by our low-swooping Lunar Orbiters, manned-landing sites have already been chosen. By plying a tiny ditch-digging tool at one of them, our soft-landed Surveyor III has tested the lunar soil and found it good to land upon. The actual Flight of the Bug can come before 1970, NASA leaders still say—and now we can foresee in detail what it will be like:

Readying the Bug. The Bug's descent begins from a circular orbit, about 90 statute miles above the lunar surface, in which the Command and Service Module (CSM) and the Lunar Module (LM) have been

Continued

High gate...low gate...touchdown...and we set foot on moon

swinging around the moon. Thrice they have crossed the moon's front side so that earth tracking stations could nail down the orbit's precise shape.

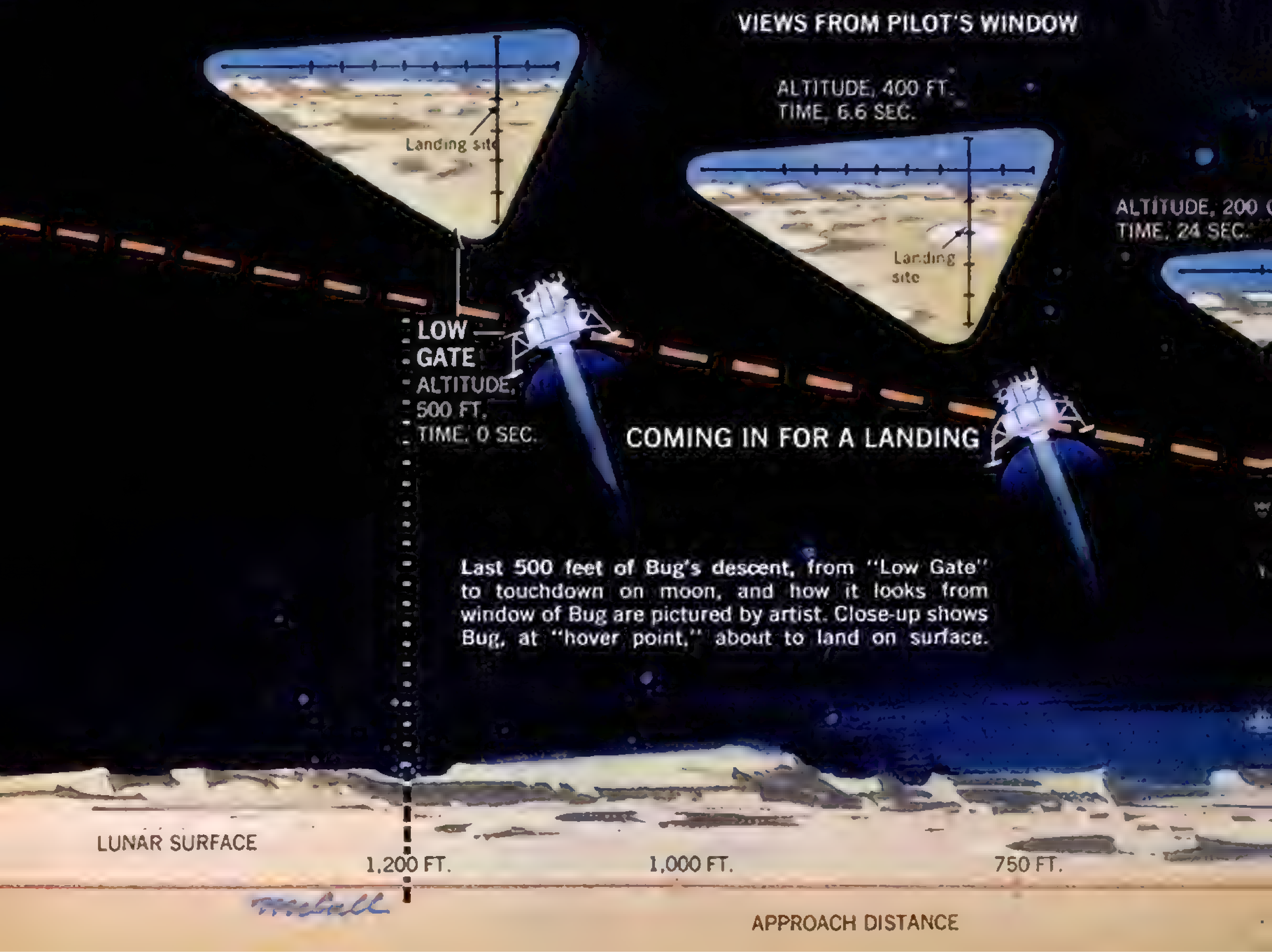
During this period of about 5½ hours, the two astronauts who are to land on the moon have gone through a crawl tunnel from the Command Module (CM) to the LM. They have turned on the Bug's equipment; checked its life-support system and its communications with the CM and the earth; aligned its gyroscopic platform, the heart of its inertial guidance system; and transferred needed data from the CSM computer to the LM computer. Meeting with no major hitch, they have closed the hatches and made ready for separation.

Casting off. Release of a mechanical link in the docking collar, and a five-second blast of the LM's small thrusters, separate the Bug from the CSM. The two craft drift apart at about a foot a second.

About a minute later, the Bug slowly rotates to various positions. This gives the third astronaut, left behind in the CSM, a last chance to inspect it externally. Meanwhile the Bug's crew recheck all its critical systems in the "LM-alone" configuration—especially the LM rendezvous radar that will be used in returning to the CSM.

Starting down. The first power maneuver for descent takes place behind the moon. It must occur halfway around the moon from the landing site, and we want the Bug to touch down on the visible side of the moon.

[Continued on page 158]



Last 500 feet of Bug's descent, from "Low Gate" to touchdown on moon, and how it looks from window of Bug are pictured by artist. Close-up shows Bug, at "hover point," about to land on surface.


THE
BUG
HOVERS
WINDOW
WINDOW
THRUSTERS
COPILOT
PILOT
HATCH
THRUSTERS
UNITED STATES
ROCKET ENGINE
CHECKING DESCENT
LANDING
PAD
TILT
ANGLE,
11°
Landing site
Landing
site
ON
SURFACE
HOVER POINT
ALTITUDE, 100 FT.
TIME, 50 SEC.
TILT
ANGLE,
0°
TOUCHDOWN
250 FT.
0 FT.
100-FT. LANDING SITE

How We'll Land on the Moon

[*Continued from page 46*]

With the Bug positioned to point its 10,000-pound-thrust descent rocket engine in the direction of its orbital flight, a 32-second firing retards its speed by the moderate amount of about 100 feet a second (68 m.p.h.).

This puts the Bug into a "transfer" orbit, ranging in altitude from a high point of 90 miles down to a low point of only 50,000 feet. It takes the Bug about an hour to coast from the high point, where the retarding thrust was applied, to the low point 180 degrees away. During this hour, the Bug's crew see the earth reappear over the lunar horizon, and can resume direct communications with tracking stations and the mission director on earth. (Before this, they can track their own flight path; their rendezvous radar shows their distance and direction from the CSM, whose orbit already has been determined.)

Braking. A second and crucial power maneuver begins at the 50,000-foot low point of the transfer orbit.

Again the LM descent engine fires ahead. It burns this time for almost eight minutes, while the Bug covers a 250-mile distance—and slows it by a whopping 5,200 feet a second (more than 3,500 m.p.h.). This braking kills almost all forward speed, and turns the Bug's near-horizontal flight path into a near-vertical one. It commits the Bug to landing now or never.

"High Gate." From nine miles away, the crew can first see their landing site. It appears in their windows if they pitch the Bug upward about 40 degrees. At this point, called the High Gate, altitude is down to 8,000 feet and forward velocity to 450 feet a second (about 300 m.p.h.)—and here the Bug enters the final landing-approach phase.

Landing approach. The next 90 seconds—the final approach—give the crew time to choose the best landing spot within range of their fuel supply.

Standing at the pilot's right, the copilot calls out a pair of figures that the guidance computer flashes upon a digital display board. They tell the pilot, using a grid pattern etched on his window, where the automatic guidance system intends to land the Bug.

If another spot looks smoother and better to the pilot, he moves a hand control toward it. This tells the automatic system to change the target. Its computer produces new figures. Again the copilot reads them off. This is repeated until the pilot is satisfied, and no longer interferes.

"Low Gate." The approach ends and the landing phase begins at what is called the Low Gate. Here the Bug is 500 feet up and 1,200 feet from its landing spot. Its velocity is down to 50 feet a second (34 m.p.h.) forward, and 15 feet a second (10 m.p.h.) downward.

From skimming along on its side, the Bug has been gradually pitching to an upright attitude, and its descent engine—still firing, but at reduced thrust—has begun to check its fall.

At 100-foot height the Bug reaches a "hover point" where its horizontal velocity should be down to zero. Tiltless now, and braked by its downward-pointing rocket engine, it descends at a rate of five feet a second. At 50 feet, this is cut back to 3½ feet a second.

Touchdown. When the Bug's landing pads are still 50 inches above the ground, probes extending down from them touch the lunar surface and light a signal lamp in the cockpit. The pilot cuts off the descent engine. A moment later, a slight jar tells the astronauts they have landed on the moon.

Had the site proved unexpectedly forbidding, the crew could have aborted a landing and returned to the CSM, by firing up the ascent stage's engine and cutting loose the descent stage. Studies show such an abort is feasible even as late as during actual touchdown, if the Bug starts to tip over because of a steep slope, treacherous soil, or insufficiently checked horizontal speed.

Plans for early Apollo flights are to stay on the surface no longer than about 18 hours, to avoid overtiring the astronauts. Part of this time will be needed to prepare the Bug to return.

The ascent. The Bug's ascent stage takes off soon after the CSM passes overhead. For 12 seconds the climb is vertical. Then the inertial guidance system tilts the flight path until it becomes ex-

Continued

actly horizontal at an altitude of 50,000 feet above the surface of the moon.

The 3,500-pound-thrust engine is cut off after about 6½ minutes. By this time the horizontal velocity is slightly more than enough for a circular orbit. So the ascent stage coasts upward through a "transfer" ellipse, rising in an hour from a low point of 50,000 feet to a high point of about 35 miles.

At the high point a modest boost from the LM's small attitude-control thrusters, increasing speed by anywhere between 10 and 100 feet a second, suffices to put the Bug into an "intermediate" orbit reaching an altitude somewhere between 35 and 75 miles. This orbit's adjustable period of revolution serves to compensate for any imprecise timing or unavoidable delay in the ascent stage's takeoff from the moon.

Earth tracking stations determine the LM's flight path in this intermediate orbit, and powerful earth-based computers help figure out the best rendezvous strategy. It is desirable for rendezvous and docking with the CSM to take place over the visible side of the moon and in sunlight.

Rendezvous. Because the Bug is orbiting at lower altitude than the 90-mile-high CSM, its period of revolution is shorter, and so it will gradually overtake the CSM.

When the Bug is only 30 to 50 miles behind the CSM, the "terminal phase" will begin. Another burst of the LM's thrusters augments its velocity by something like 20 feet a second. By this maneuver, it not only catches up but also gains altitude to reach the level of the CSM. Another hour of free coasting closes the gap between the two craft to a distance of about 3½ miles. Their relative speed is now less than 30 feet a second (20 m.p.h.).

A number of very short bursts, monitored visually and by radar from both craft, finally bring the LM to the actual docking with the CSM.

With successful docking, the Flight of the Bug comes to an end. The two astronauts enter the CSM and rejoin its shipkeeper. The Bug is detached, and the three in the CSM head for earth—still 238,000 miles away. PS

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MONTHLY

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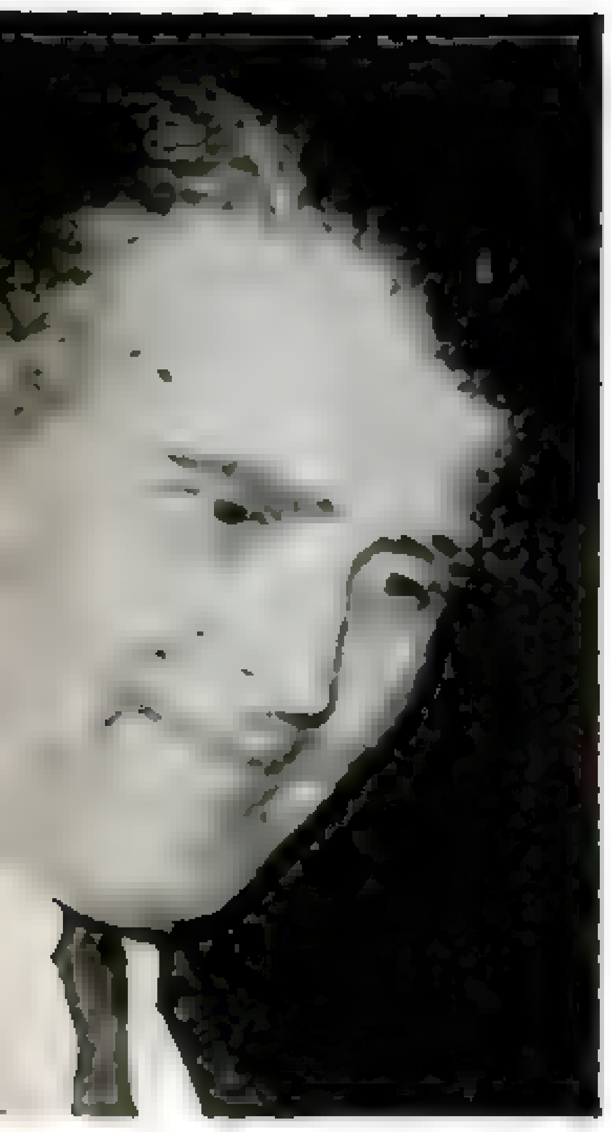


That Puzzling Problem for Space Launches...

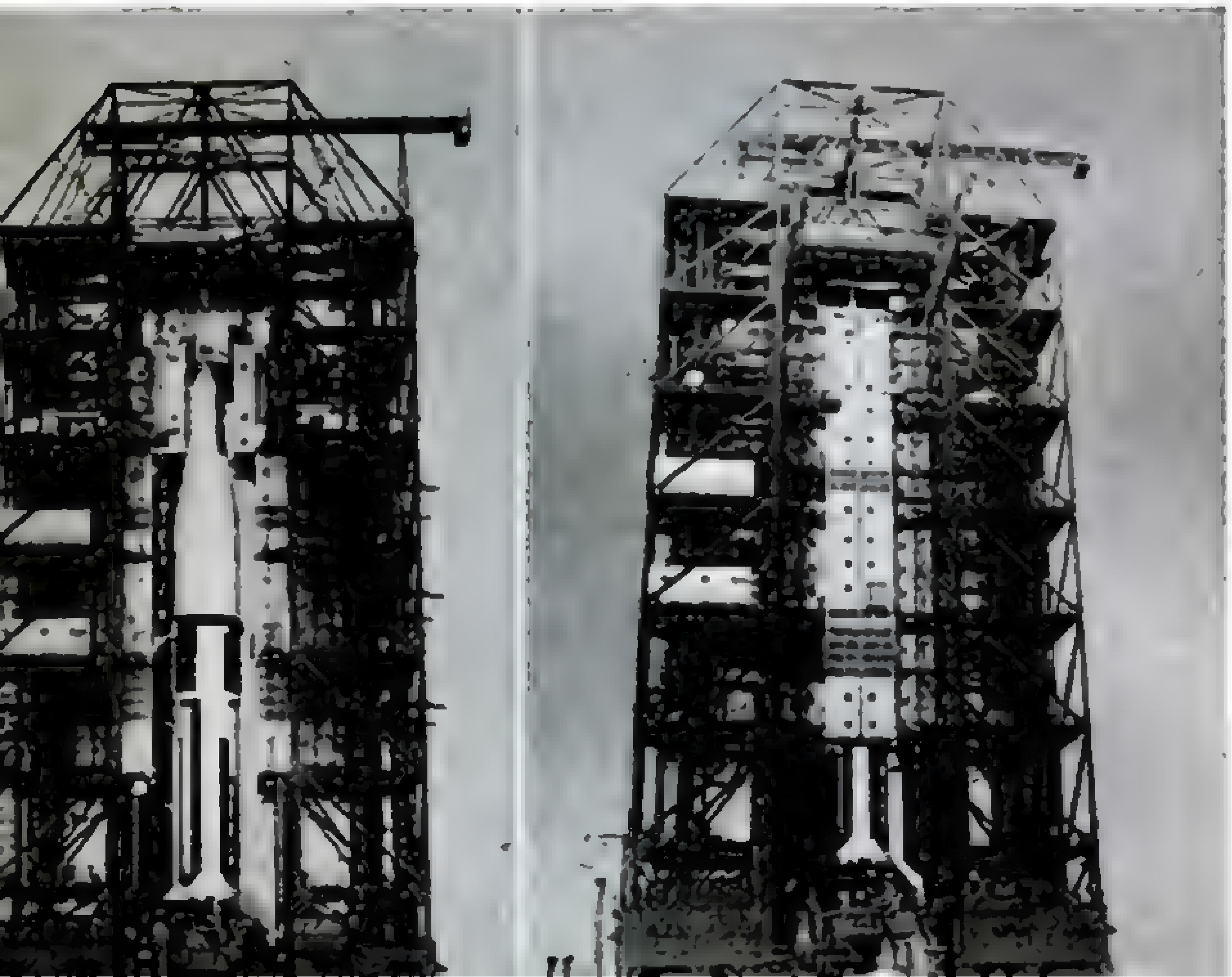
WEATHER

By DR. WERNHER VON BRAUN
Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

A manned space launch is planned for 11:00 a.m. Now the weatherman predicts that a strong squall line will pass through the Cape Kennedy area around 1:00 p.m. Should launch preparations go on, in the hope of getting the rocket off the pad before bad weather arrives? Or would it be better to scrub for the day, get the astronauts out of the spacecraft, and secure the bird by closing clamshell doors around it?

The decision hangs on many things. How likely is it that there will be no delays in the countdown? (The answer may depend on the maturity of the flight hardware and the complexity of the mission.) What is the present weather and the forecast in the ocean area east of the Cape, in case of a launch abort and a water landing of the spacecraft? And what is the weather situation in the intended landing area, which may be in the Pacific, after a successfully completed space mission?

Clamshell panels on gantry, open in view at left below, close around Uprated Saturn I, as in other view, to shield it from high winds—and sometimes more dangerous flying debris that comes with them.



Also to be weighed: How important to a mission's success is the launch date originally planned? Suppose a rendezvous is to be made with a spacecraft already in orbit. A launch delay of 24 hours may exceed the target's fuel reserves, and make it impossible to carry out the rendezvous at all.

Scrub changes moon plans. In a future Apollo flight to the moon, a scrub for the day will always postpone a launch for two to four days, the "recycle time" needed for starting over again. This means changing the lunar-landing site. It may seem strange that the weather in Florida affects where we land on the moon, but here is why:

With present technology, a moon landing requires lighting that shows up the lunar terrain's relief with good contrast. When the sun is high, the contrast is poor. But it becomes satisfactory when the sun is seven to 20 degrees above the lunar horizon, so that long shadows are cast by crater rims, mountains, and boulders.

You can see with your unaided eye, during a waxing moon, how the line of sunrise—the "terminator"—travels from right to left across the moon's face. Sunrise, of course, means a local sun elevation of zero degrees. So our magic landing zone of seven to 20 degrees always trails the terminator, staying on its right-hand or sunlit side.

Therefore, if a crew has planned to land on the right side of the moon's face, a weather-caused delay of a few days may require shifting the landing area to the moon's left side.

Thus even a simple squall line can seri-

An expert tells how storms and high winds affect takeoff plans—and why the forecast for Florida may even fix the site for a manned landing on the moon

Hurricane shelter is provided by huge Vertical Assembly Building, from which giant crawler is carrying a mighty Saturn V rocket to pad for ground tests. Advance warning of last year's Hurricane Alma sent this rocket back to safety of building—an 11½-hour moving job.

ously interfere with a well-laid-out plan for a space operation. And weather problems become more complex, when we consider the various phenomena that can affect space activities.

A small hurricane is reported off Martinique in the Lesser Antilles. In five days it grows to a full-blown killer, threatening Cuba. Will it head next for Mexico, Louisiana, or Florida? Nobody has any idea.

All the while, launch preparations at the Cape go on—but, for each day of uncertainty, the launch director has his contingency plan ready. It takes time to secure an Atlas-Agena or an Uprated Saturn I on its launch pad, and even more time to move a giant Saturn V about 3½ miles back from its pad to the hurricane-proof Vertical Assembly Building.

Electrical-storm effects. On or near Cape Kennedy, thunderstorms occur on 75 of the 365 days of a year. At the Saturn V launch complex, both the Vertical As-

Continued

Hydraulic damping arm for Saturn V, shown being tested prior to use, reduces vibration of rocket caused by surface winds at the pad. It counters effect of "vortex shedding," or separation of sideward eddies downwind of the rocket—the same phenomenon that makes a flag flutter and a telephone wire sing in the wind.

sembly Building and a Launch Umbilical Tower are likely to be struck by lightning about once a month during June, July, and August, it is estimated. But lightning-rod systems ground the flashes harmlessly.

But even from a distant thunderstorm, atmospheric electricity can cause corona discharges from sharp points of a space vehicle or its umbilical tower. Precautions must be taken against the possibility that this phenomenon could ignite combustible rocket gases, such as hydrogen.

Rain and wind. Rain is less of a problem in rocketry than it used to be. There was a time when launches were plagued with insulation breakdowns due to humidity in connectors, or drenched cable tunnels. Better cables, plugs, potting compounds, and airtight boxes for electronic and electromechanical components have all but ended these difficulties. Just as a quietly falling rain is unlikely to delay your airliner, rain does not greatly interfere with space operations today.

Wind, however, seriously affects a space vehicle's design and operation. The problem begins even before flight, since a towering space rocket must be able to withstand surface winds. They have three distinct effects:

- *Steady wind load* acts on the space vehicle with a constant force like that on a sail.
- *Turbulence*, or gusting wind load, superimposes varying forces upon the steady wind load.
- "*Vortex shedding*" is the phenomenon that makes a flag flutter, or a telephone wire sing in the wind. Eddies, created downwind of a flagpole, wire, or rocket, separate alternately on opposite sides. The reactive force makes the flag, wire, or rocket vibrate at right angles to the onrushing wind. This motion exerts cyclic bending forces on a space vehicle.

It would not be practical to build a space rocket strong enough to withstand the most violent ground-wind forces, yet light enough to give the desired performance. Airliners are not designed, either, to ride out a hurricane on the loading ramp. But they can be flown out of the endangered area. Space vehicles cannot.

So space rockets must be protected from excessively high winds, and the often more dangerous flying debris that comes with them, by clamshell-type enclosures or hurricane-proof buildings. Hydraulic damping devices, of which an example is illustrated in the photograph above, are sometimes used to reduce the vibration caused by the phenomenon of vortex shedding.

After the takeoff. An ascending rocket encounters high-altitude winds. A large space vehicle, passing at supersonic speed through a 150-knot jetstream at 35,000-foot altitude, may undergo bending forces that would break it up in midair if it were not designed to resist them. Actually its design represents a practical compromise, made by weighing the frequency of particularly violent winds against keeping the performance of the rocket up. Then, upper-air meteorology must tell whether it is safe to launch on a given day.

Weather affects space operations in other ways. A storm may hinder moving a large rocket stage to the Cape by ship or air. Persistent bad weather may interfere with static tests or launch preparations, and lead to corrosion problems with flight hardware and ground-support equipment.

Finally, despite advanced electronic and tracking techniques, some launches may still demand a cloudless sky for photographing the bird's flight. PS

The '68 CARS—We Pick 13 Winners

OCTOBER CENTS

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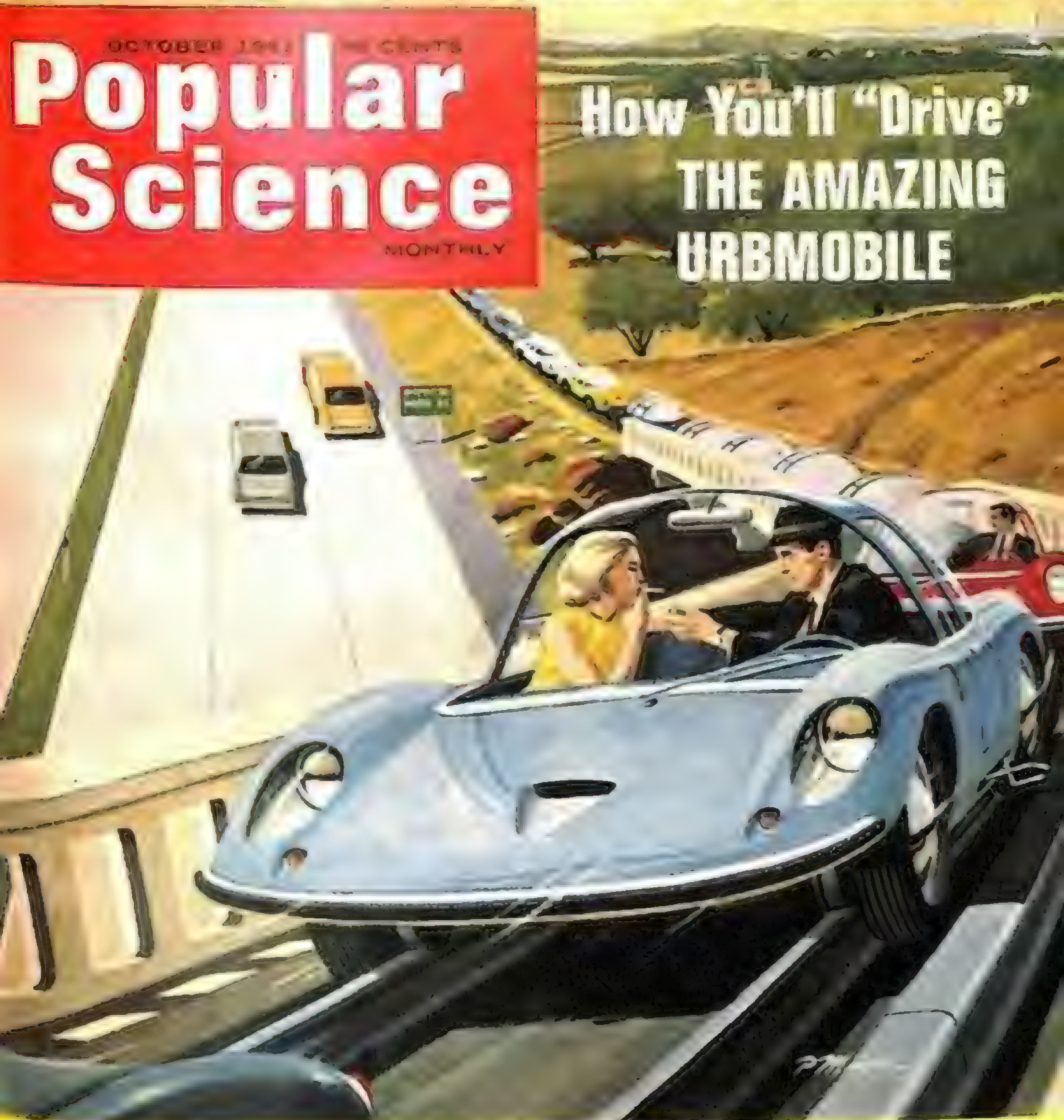

How You'll "Drive" THE AMAZING URBMOBILE

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will work this way. Hydrogen from pump, after cooling nozzle, streams through white-hot core of reactor. Blast of heated gas from nozzle propels rocket. Tapped-off hydrogen drives turbopump, and exhausts through small nozzles that can control attitude or augment thrust.

HOW WE'LL TRAVEL BEYOND THE MOON

Nuclear rocket engines of mighty power, needed for our manned voyages of the future to other planets, are being perfected in current firing trials in Nevada

By DR. WERNHER VON BRAUN

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

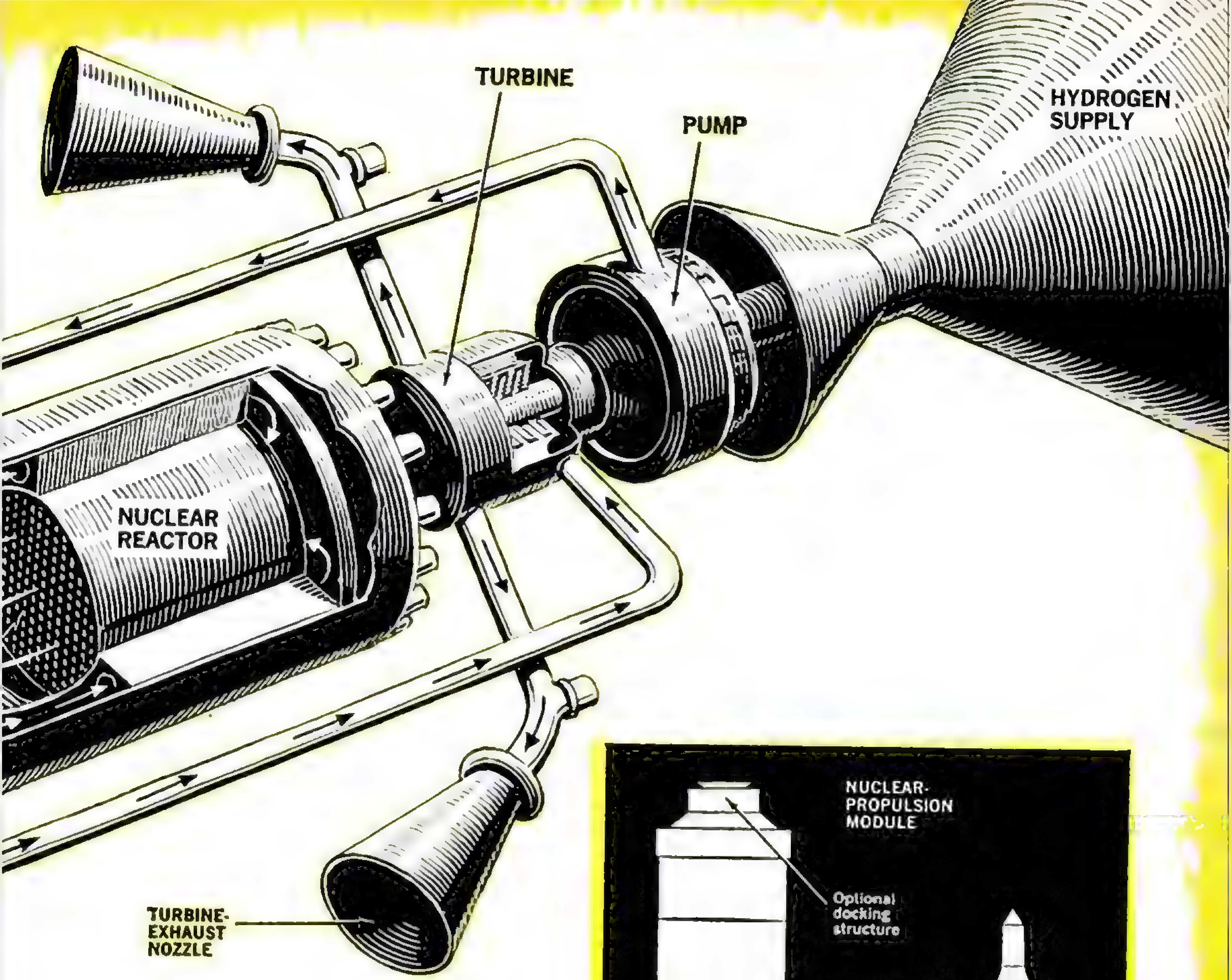
Successful tests have lately brought a flyable nuclear rocket engine within predictable range—eight or nine years and upward of $1 billion more, by a current estimate. Should we buy it?

Backed by the President, AEC and NASA recently asked funds to go full steam ahead. In authorization bills, Congress tentatively approved most of the amount sought for the coming year.

Still pending, as this was written, was Congress' final action on the agencies' actual appropriations. There was a question whether economy-enforced cuts might defer the full-scale nuclear-engine effort. But, sooner or later, it looked bound to come. Here, Dr. von Braun tells why.—The Editors.

NERVA, a nuclear rocket engine with a thrust of 200,000 to 250,000 pounds and a reactor power equivalent to about 6,700,000 horsepower, will one day enable astronauts to visit the planet Mars. It will give us enough rocket power to fly a sizable group of explorers to the moon without stopover and rendezvous in lunar orbit. It will support these explorers with a cargo-carrying system that can land much greater loads on the lunar surface, and reduce the cost of transporting them.

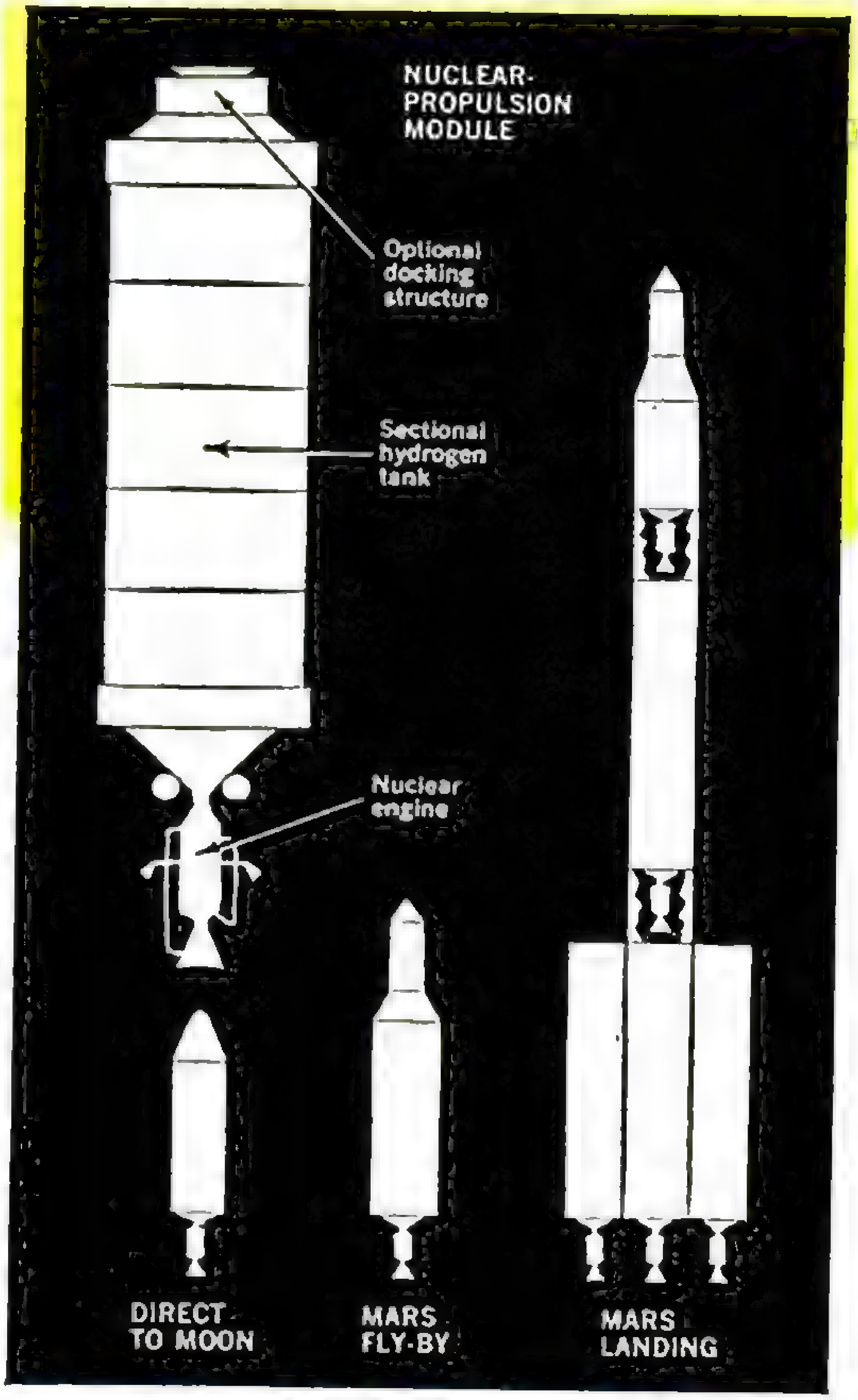
The NERVA engine, whose name stands for Nuclear Engine for Rocket Vehicle Application, is the goal of a nuclear-rocket program jointly sponsored and conducted since 1958 by the Atomic



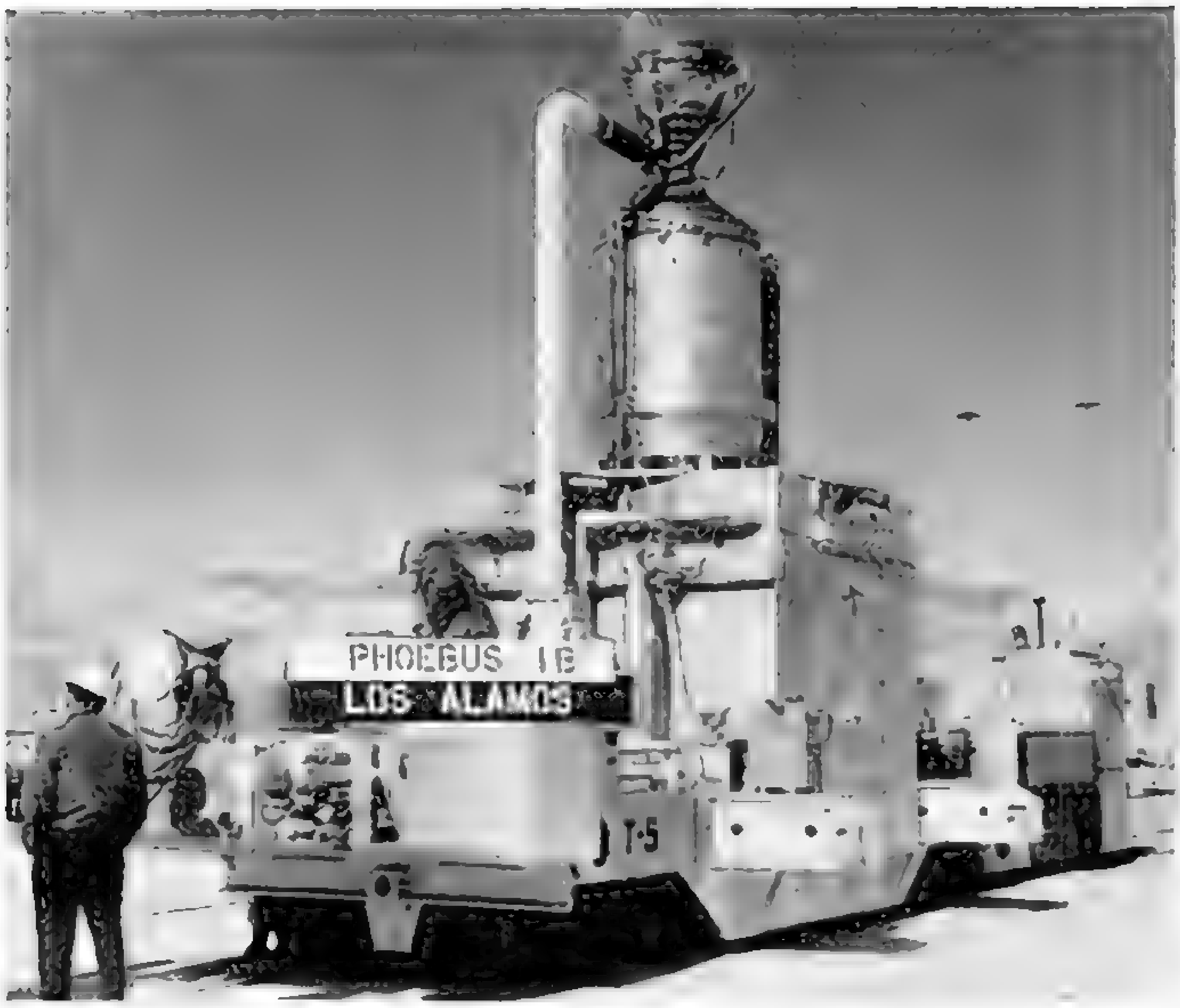
Energy Commission (AEC) and the National Aeronautics and Space Administration (NASA).

How NERVA will work. Heart of the NERVA engine will be a nuclear reactor built of graphite, and perforated by thousands of tiny channels through which hydrogen is pumped. Uranium 235, embedded in the graphite, forms the reactor's fuel. Its neutron chain reaction releases a continuous heat flow of five million thermal kilowatts, and the core of the reactor glows white-hot.

Continued



Manned spacecraft for missions shown can be made up of one or more nuclear propulsion modules, each consisting mainly of NERVA engine and tank holding 50 to 175 tons of hydrogen propellant.



Nuclear-rocket reactor Phoebus 1B, seen atop rail car, developed 2,000,000 hp. and proved NERVA engine feasible in test this year.

As hydrogen streams through, at a pressure of several hundred pounds to the square inch, it is heated to more than 4,000 degrees F. Expanding, it spurts flamelessly from a conventional De Laval nozzle at 25,000 to 28,000 feet per second (17,000-19,000 m.p.h.).

The superiority of a nuclear rocket engine like NERVA lies in the fact that the exhaust is pure hydrogen, lightest of all the gases. The lighter the atoms of a propellant, the greater the exhaust velocity—and the more thrust produced for every pound of propellant expelled.

In terms of propellant economy, NERVA is expected to be about twice as good as our best chemical rocket engines burning hydrogen and oxygen, and about three times as good as the best solid-propellant rockets.

Problems to solve first. Developing such a radically new engine raises many questions requiring thorough research to answer, before design of a flyable engine system can even begin:

- How will the graphite hold out under the erosive and corrosive effect of high-pressure hydrogen, rushing at tremendous speed through the reactor's channels at white-hot temperature? Will sudden heating and cooling, during start-up and shutdown, crack the graphite?
- How large must the reactor be, to permit a continuous heat flow of five million thermal kilowatts from the graphite core to the hydrogen?
- What is the most effective way to cool the exhaust nozzle and the reactor's pressure vessel with the hydrogen, before it enters the reactor core?
- How must the control rods that regulate the reactor's heat be linked to the hydrogen-flow control, which governs the amount of propellant that absorbs and carries away all that heat?
- What safety features and procedures must be provided, to avoid a disastrous nuclear accident?

Answering these and other questions has been the aim of the joint AEC-NASA program, known as Project Rover and directed by the Space Nuclear Propulsion Office. The bulk of the pioneering work in reactor technology was done by AEC's Los Alamos Scientific Laboratory in New Mexico. NASA's Lewis Research Center concentrated on non-nuclear problems such as how to build a liquid-hydrogen-cooled exhaust nozzle—or a liquid-propellant pump powered by a turbine that would be driven by warmed-up gaseous hydrogen, tapped off the nozzle's cooling passages.

Experimental nonflying Rover reactors have served for trials. First came Kiwi-A, named after New Zealand's flightless bird and successfully tested in 1959. A dozen reactors of improved design have since been tested, all at the Nuclear Rocket Development Station on Jackass Flats, in Nevada. Progress shown by the performance of Kiwi-B4D in May, 1964, led to more-powerful reactors of a new series called Phoebus.

In June, 1965, the Phoebus 1A reactor ran for over 10 minutes at full power of about 1,100,000 kw., or nearly 1,500,000 hp. Last February, a similar sized but more powerful Phoebus 1B reactor was operated for 45 minutes. During 30 minutes, the maximum time planned, it de-

[*Continued on page 202*]

[*Continued from page 86*]

veloped about 1,500,000 kw., or 2,000,000 hp.—more than the entire electrical output of Hoover Dam.

The Phoebus 1 reactor, with a core of only 35-inch diameter, gives a thrust of about 80,000 pounds. NERVA's 200,000-to-250,000-pound thrust will require a core 50 to 55 inches in diameter. However, the core's length will remain the same, and so the length of the hydrogen passages is unaltered by the scale-up to NERVA performance.

The Phoebus 1 runs, especially the last one, prove that a NERVA flight reactor can be built successfully. This will be further demonstrated by a 55-inch Phoebus 2 reactor to be tested later this year. Phoebus 2, like NERVA, is designed for a power of about five million thermal kilowatts or 6,700,000 hp. It has already had a successful "cold flow" trial, a preliminary one before operating with a hot reactor, at the Nevada proving ground.

The projected NERVA engine, under contract for development by Aerojet and Westinghouse, will be a completely integrated, flyable nuclear-engine system based on the Phoebus reactor. When ready, it will be incorporated in a Nuclear Propulsion Module (illustrated on a preceding page) that can be used for a variety of applications. Here are some outstanding examples:

Direct-to-moon flight. The module can serve as a third stage of Saturn V, whose main diameter of 33 feet it matches. It nearly doubles the Saturn V's payload for some applications. This will permit manned flights to the moon direct—without a separate LM and rendezvous in lunar orbit.

Earth-to-moon shuttle. The same module, with a propellant tank of different length, provides a spacecraft to shuttle between earth and moon.

Moonbound passengers, arriving from earth in an orbital transport, board the shuttle in earth orbit.

The shuttle, under the power of its NERVA engine, adds to its orbital speed the 11,000 feet per second (7,500 m.p.h.) necessary to coast to the moon. Three days later the nuclear engine is turned on again for retrofire to slow the shuttle and allow it to be captured in an orbit around the moon.

An LM-type vehicle takes the moonbound passengers down to the lunar surface, after having disgorged a crew desiring to return to earth.

A third short boost by the nuclear engine drives the shuttle out of the moon's orbit again. A fourth and final blast, three days later, de-boosts it into its original earth orbit. Its hydrogen tank, now nearly empty, is refilled by an earth-to-orbit tanker for the next round trip.

Note that the propellant supply does not have to be replenished near the moon—the hydrogen need not be transported so far. Nor does NERVA's reactor need refueling with uranium 235. The shuttle could make this round trip many times with the same reactor core, and herein lies its economy.

Mars flyby. We can use the propulsion module, too, for a manned Mars flyby mission—where heavy crew supplies for a travel time of two years, and rather high velocity requirements, exceed the capabilities of an all-chemical Saturn V.

Mars landing. Finally, a cluster of propulsion modules will enable man to land on Mars.

Assembled in earth orbit, the spaceship will be started toward Mars by three modules firing simultaneously. A single "Mars-arrival" module will de-boost it into Martian orbit. Astronauts will descend to Mars' surface, and return to the orbiting ship, with a chemically powered craft based on LM and Voyager technology. Another NERVA-powered "Mars-departure" module drives the ship back to earth, where the crew will descend in a reentry capsule.

Retardation upon arrival at the earth will be with the help of aerodynamic drag only. This will be a problem in itself, for the reentry capsule will not reenter at a "sluggish" 36,000 feet per second (24,500 m.p.h.) like an Apollo Command Module returning from the moon. The reentry speed may be as high as 60,000 feet per second, or more than 40,000 m.p.h.! But heat-shield experts are confident that they will be prepared to meet that challenge, whenever NERVA is ready to do its part.

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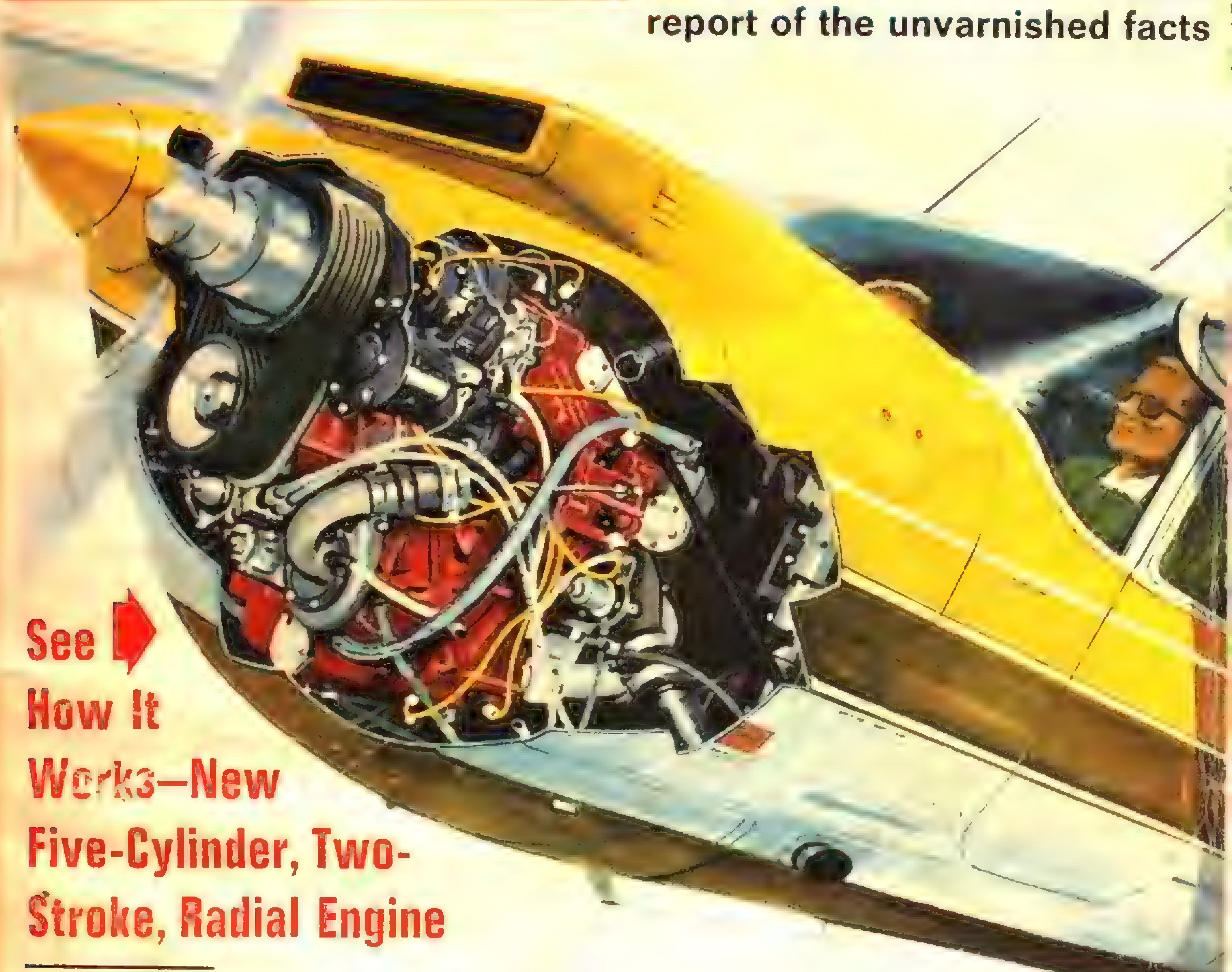
BUYING A USED CAR? "I'll Cheat You If You Don't Watch Out!" By an Odometer Artist

MY LSD TRIP

A non-cop, non-hippie report of the unvarnished facts



See How It Works—New Five-Cylinder, Two-Stroke, Radial Engine

New Non-Lethal Police Weapons to Control Riots...By ERLE STANLEY GARDNER

Biggest Naval Guns to Bc

HOW YOU CAN Buy the Righ
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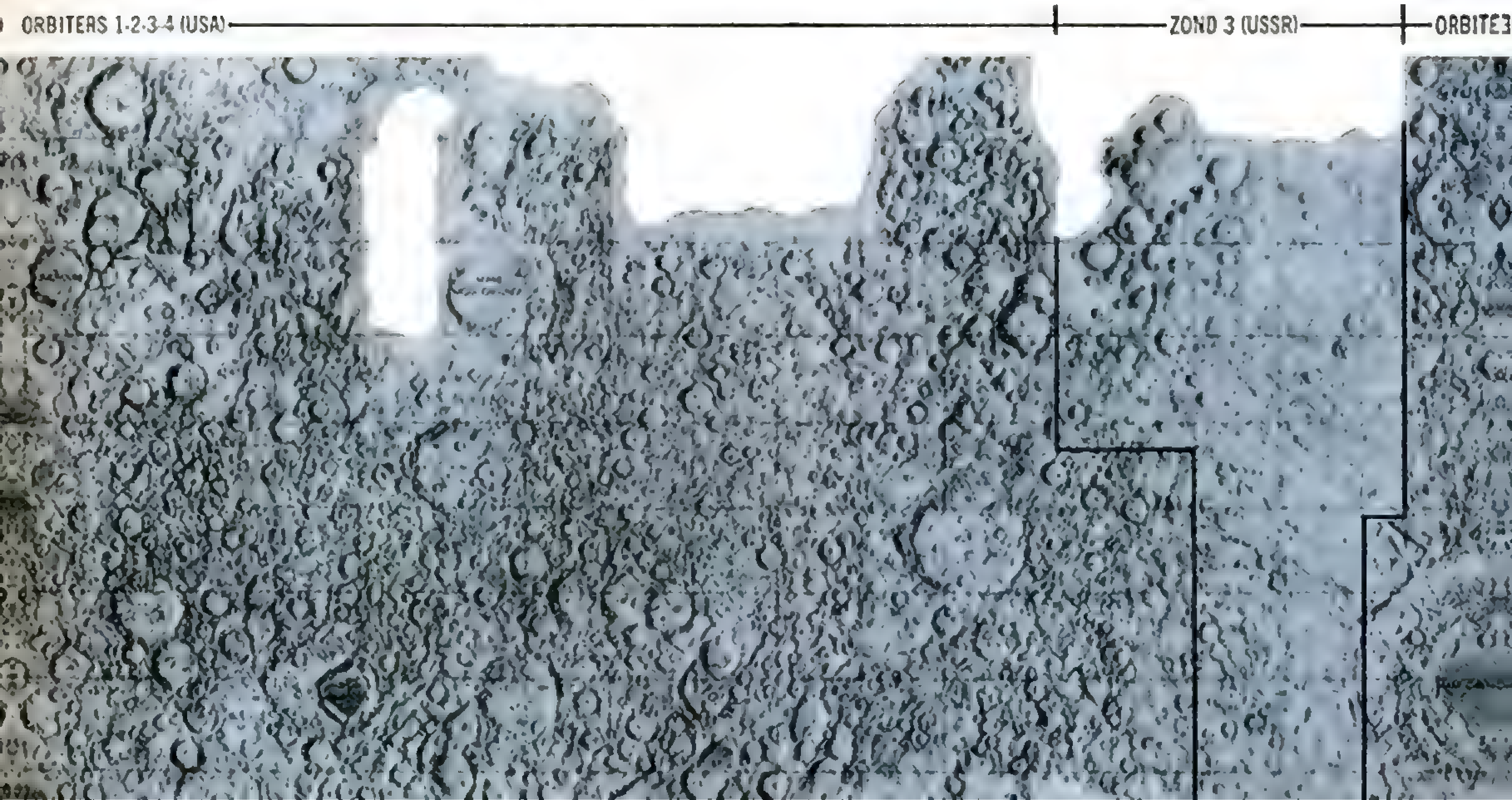
Most spectacular sight of moon's far side is gigantic "bull's-eye" of Orientale basin—seen head on in this magnificent Orbiter 4 photo from 1,690-mile height, and charted at far right of map below.

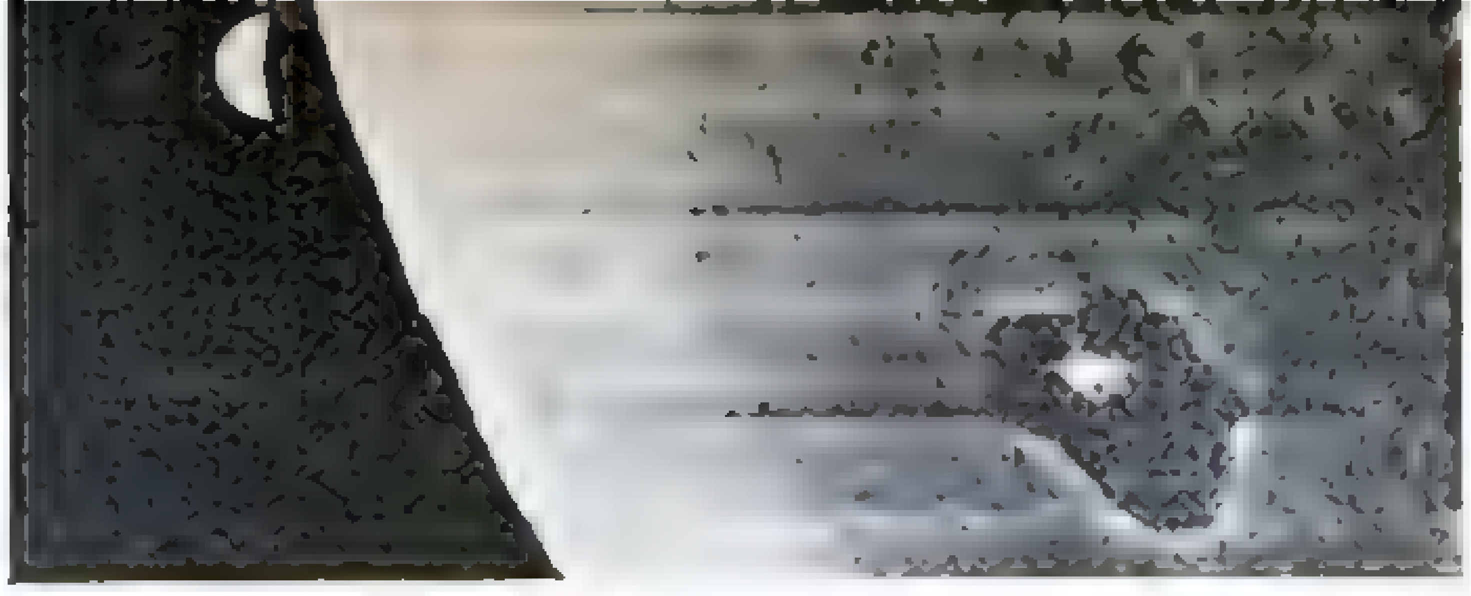
What's o

By DR. WERNHER VON BRAUN

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

A history-making feat of astronomical exploration, begun by Russian spacecraft and now completed by our Lunar Orbiters, bares the secrets of the moon's hidden half





Making first U.S. photos behind the moon, Lunar Orbiter 1 scans mysterious hidden side (foreground), and looks back past it at earth (small crescent).

the Other Side of the Moon

When Orbiter 5 radioed its final pictures to earth late last August, what was behind the moon was a mystery no longer. Brought to completion was the achievement of photo-mapping the moon's far side—the part, perpetually hidden from earth, that astronomers long had thought would never be seen.

That history-making feat climaxed a whole series of photographic triumphs by our five Lunar Orbiter spacecraft. With unprecedented clarity and high resolution, their cameras pictured lunar landscapes previously explored only by telescope from earth. Dramatic slant-angle views peered into famous craters' gaping depths. Overhead shots looked squarely down at scenery on the moon's rim, visible from earth only at a grazing angle. Behind the moon the Orbiters did most of the mapping and by far the best, in being the most-detailed.

Russian craft gave first look. Our Orbiters were not the first spacecraft to view the other side of the moon. Its exploration began on Oct. 7, 1959, when the Soviets' Luna 3, flying past in a long-stretched elliptical trajectory, took the first pictures of the unseen side from a distance of about 40,000 miles. At the critical time of picture-taking, Luna 3 was directly between the sun and moon, and so its full-moon photos lacked the shadows needed to discern more than a few conspicuous far-side features.

In 1965, another Soviet probe, Zond 3, flew past the moon's far side at less than 7,000-mile distance and obtained better, sidelighted photos. They were subsequently used to assemble a partial map of the hidden side.

Our own Lunar Orbiters may have been Johnny-come-latelies, but the superior quality of their pictures makes up for it. Through them we now know both sides of the moon better than our own earth. Their photos are so close-range and sharp as to reveal even the tracks left by boulders rolling down a lunar hillside.

What the far side is like. The pictures show the moon's other side to be quite different from the one facing us.

An outstanding discovery is the far side's lack of large mares, or "seas," the smooth dark plains that form the facial features of the Man in the Moon. These mares, being free of steep mountain ranges, were selected as landing sites for our Surveyor spacecraft and for our coming manned landings. In contrast, the terrain behind the moon appears thickly cratered and rugged.

Instead of mares, at least three great basins surrounded by concentric rings of mountains have been discovered on the moon's far side. It has been proposed to call these remarkable formations "thalassoids," which is Greek for sea-like.

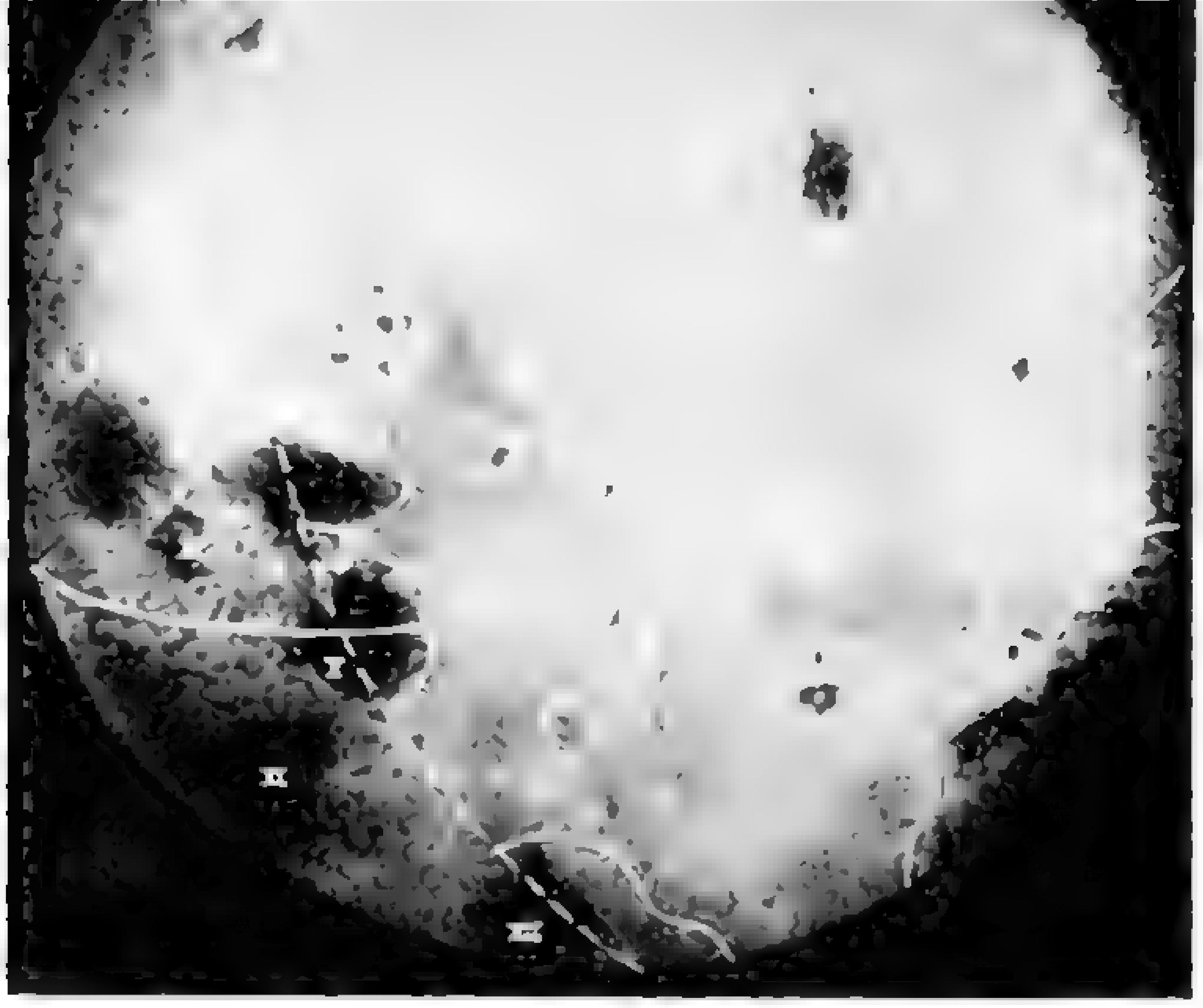
A huge "bull's-eye." Largest of the thalassoids is Orientale basin, ringed like a target's bull's-eye with seven circular mountain chains. Between outermost rims, the gigantic formation is 600 miles in diameter. It is such a spectacular find that Dr. Gerard Kuiper, eminent University of Arizona astronomer, was moved to comment, "If it were fully visible on the side of the moon facing the earth, a whole mythology would have been built up around it."

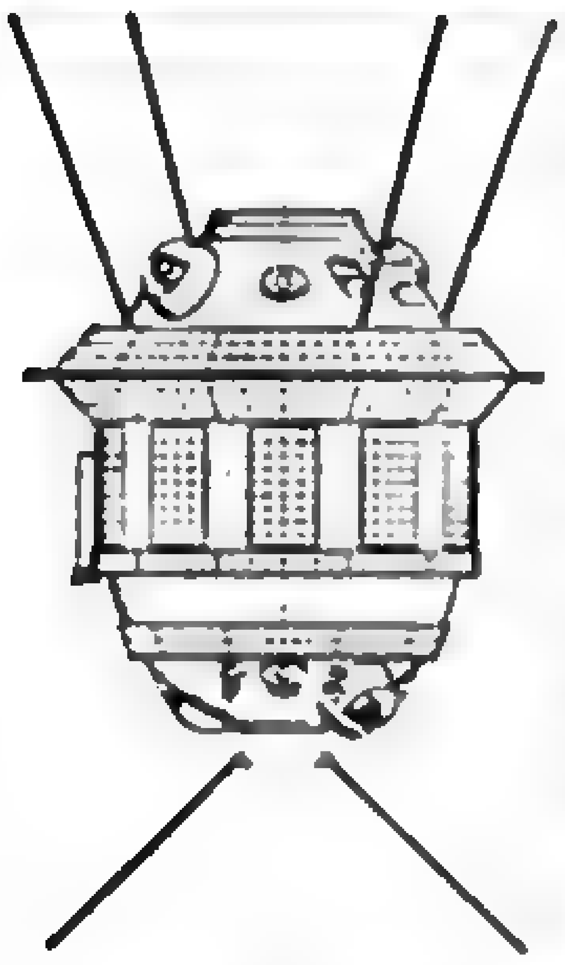
Actually the major part of this forma-

Continued

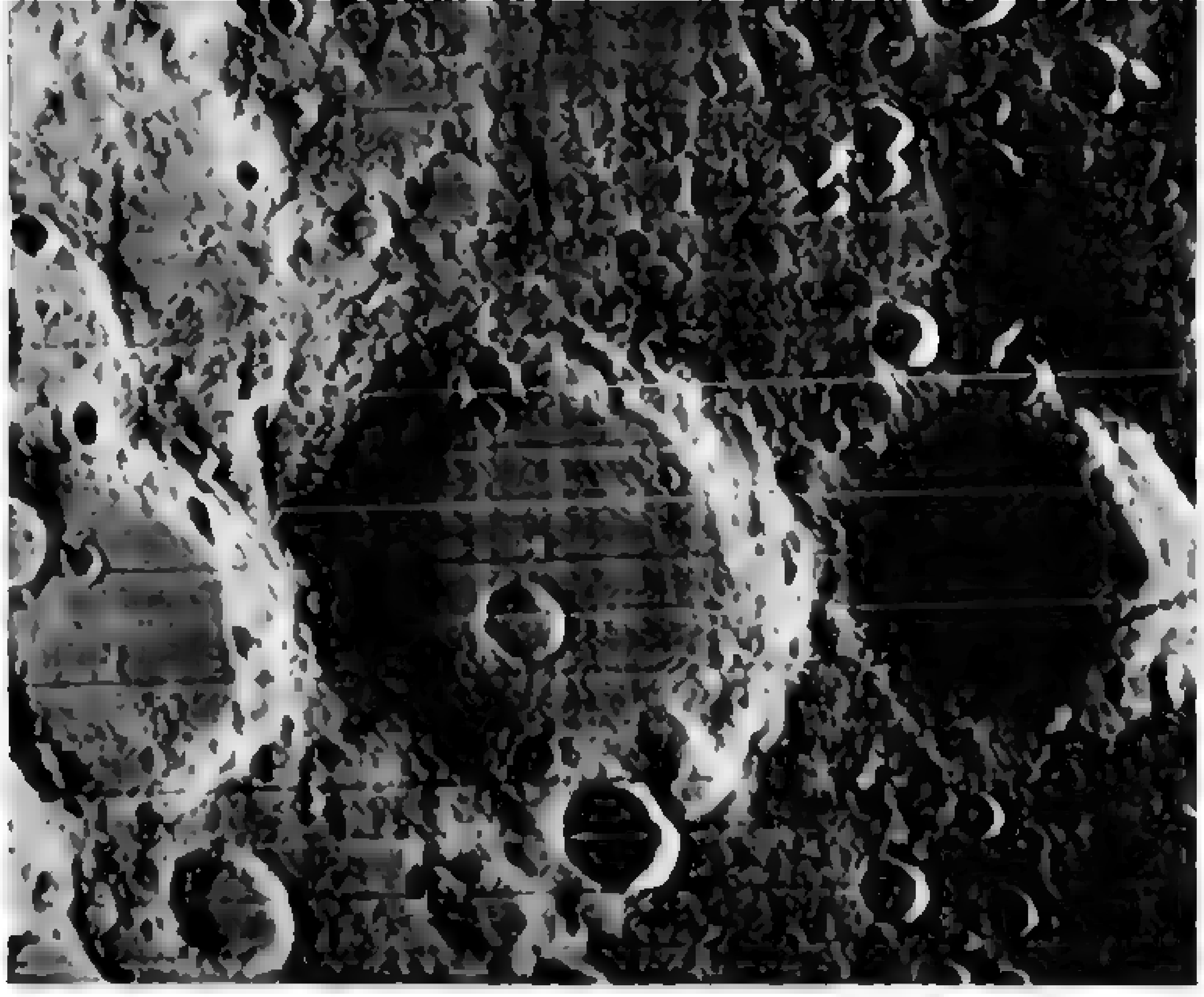
A U.S. map of the moon's hidden side—before Orbiter 5 filled in the blanks

Central part of historic "Lunar Farside Chart" presented by U.S. at Prague last August is based on photos by Orbiters 1-4 and Zond 3, whose respective contributions are shown. Two semicircular parts, not pictured, cover regions nearer poles and come solely from Orbiter 4 views. Unexplored areas (white blanks) have since been mapped by Orbiter 5. Orbiters' discoveries end long Soviet monopoly on proposing names for features of far side.





First view of moon's far side, above, was from Russia's four-foot-diameter Luna 3 (inset).



Latest views' remarkable quality is shown by Orbiter 5 photo of hitherto-unknown craters, at site within one of blank spots of earlier far-side map.

tion lies just beyond the western, or left, edge of the moon's near side. Just enough of it extends into the visible face to have been glimpsed from earth, and to have been named Mare Orientale—before astronomers knew what the whole of it really looked like.

The impact of a colossal meteorite, 30 to 60 miles in diameter, is believed to have formed Orientale basin's 186-mile-wide circular plain and its rings of mountains—of which the outermost, the Cordillera Mountains, rise to 20,000 feet. At the foot of the next inward ring, a dark irregular area looks to geologists to be filled with volcanic material that welled to the surface after the impact. Telephoto viewing reveals chunks thrown from the basin—and even radial lines showing their trajectories. The mountain ranges, on the whole, look much like the concentric ridges that would be formed if a boulder crashed into a pond covered by a foot-thick layer of ice.

Christening the finds. Giving the new-found lunar features their names—which are bound to be permanently enshrined in future textbooks and maps—makes an interesting sidelight of the Soviet-U.S. competition in exploring the other side of the moon.

For features visible in Luna 3's photos, the Soviet Academy of Sciences proudly and promptly proposed names including the Moscow Sea, the Tsiolkovsky and Lomonosov craters, and the Soviet Mountains. Zond 3 brought the number of Soviet-proposed names for new features to a total of 228.

Then came our turn, as a result of our Lunar Orbiter program, managed by NASA's Langley Research Center, Hampton, Va. As NASA's Orbiters explored the back of the moon, and made additional discoveries, a committee of our National Academy of Sciences likewise set about drawing up a list of American-proposed names for them.

Last August, when the International Astronomical Union met in Prague, Czechoslovakia, the Soviet and American delegations both came prepared to offer their lists of names for adoption. The Russian astronomers brought along a map locating the Soviet finds. In turn, the Americans presented a newly produced "Lunar Farside Chart"—already bearing several of the Russian-proposed names, and compiled with an assist from Zond 3, but mostly based on mapping by Lunar Orbiters 1 to 4.

Comparing the charts revealed discrepancies—and both were incomplete. Even as the U.S. map was exhibited, Orbiter 5 was charting its blank spaces.

So the Americans proposed, and the Russians agreed, to defer the formal christening for three years. By then a complete, internationally accepted map of the moon's far side should be available. Meanwhile, the IAU decided, it would designate far-side craters and other features simply by numbers. How many will ultimately get names may be gauged by the more-than-700 named features of the moon's visible face. PS

1968

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Now! ELECTRONIC FUEL INJECTION ...more power, better mileage, and less air pollution

McNAMARA'S MISSILE DEFENSE

A Multibillion-Do ... WYLIE

How We Broke 266 Spee ... otor Shop

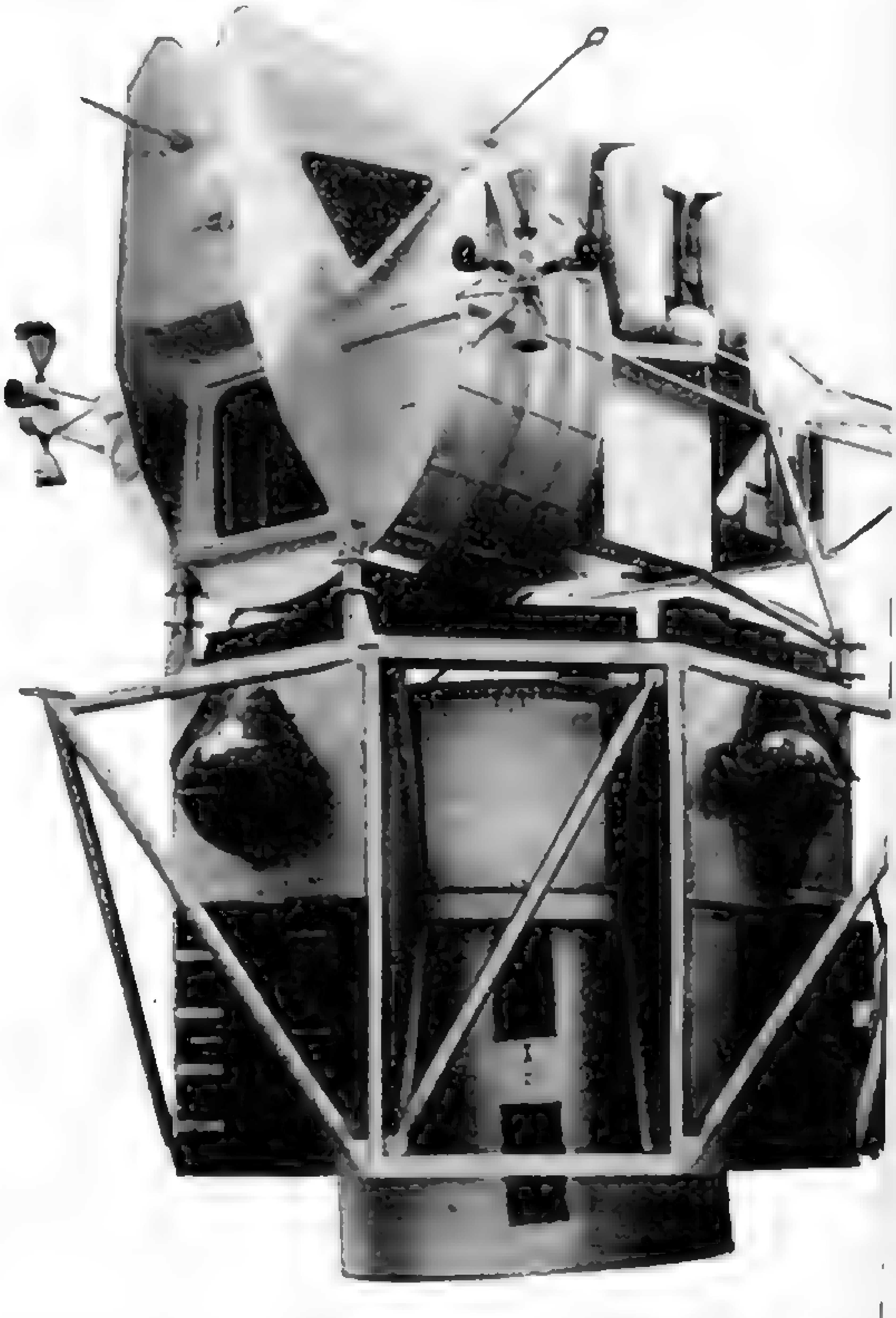
with Camaros—by Smok ... Power Hacksaw from a Kit

Astronauts will train telescopes on sun from a

Manned Observatory in Space

By DR. WERNHER VON BRAUN
Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

Here is a preview of a coming spacecraft that will provide our first outpost in orbit for a crew of astronomers

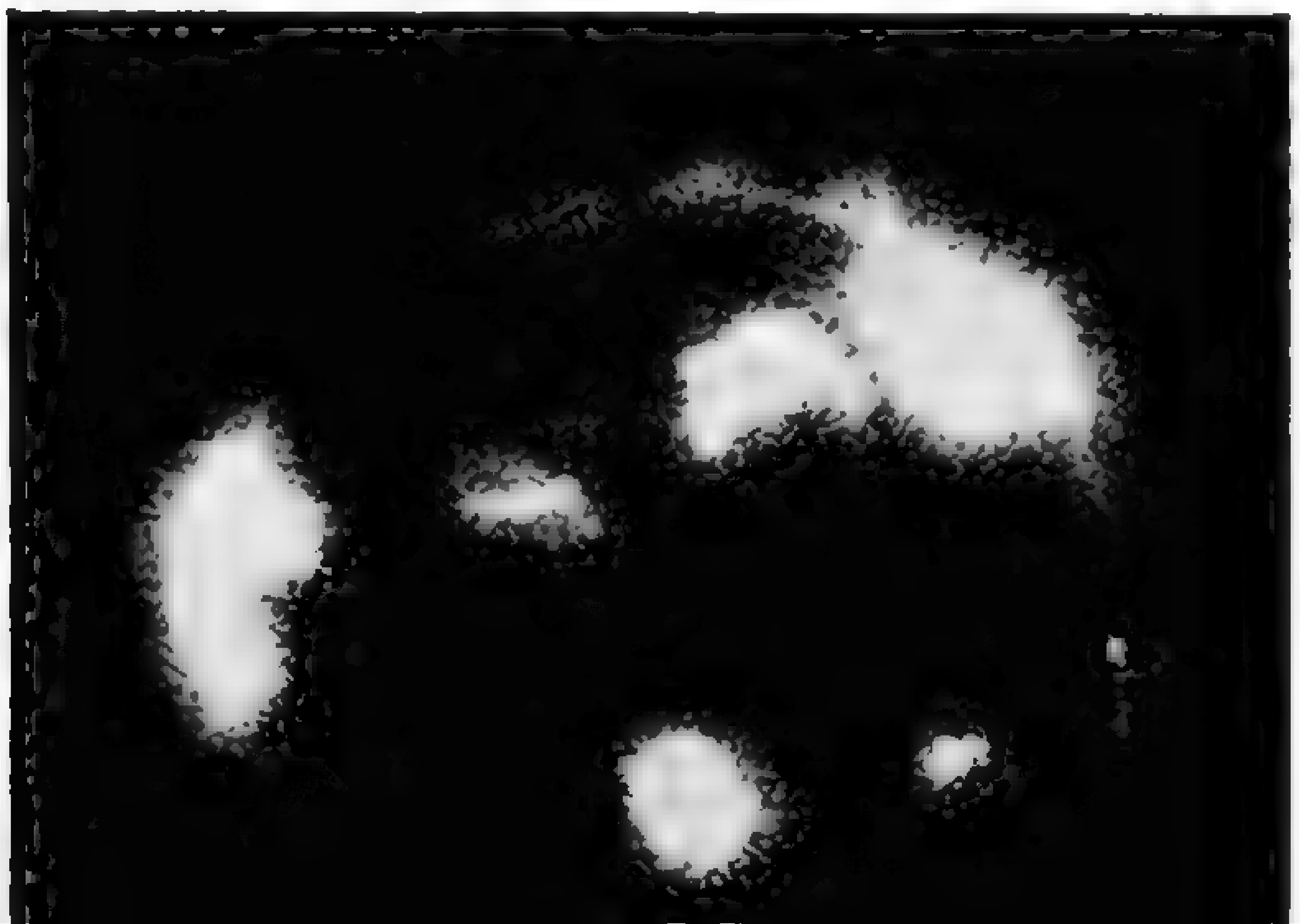


A year or so after our first Apollo manned landing on the moon, NASA hopes to place in orbit around the earth our first manned astronomical observatory.

The Apollo Telescope Mount or ATM, so called because it draws heavily on hardware developed for the Apollo program, will be operated by two astronaut-astronomers. It will be a spacecraft carrying the most powerful array of instruments ever assembled to probe the mysteries of the sun.

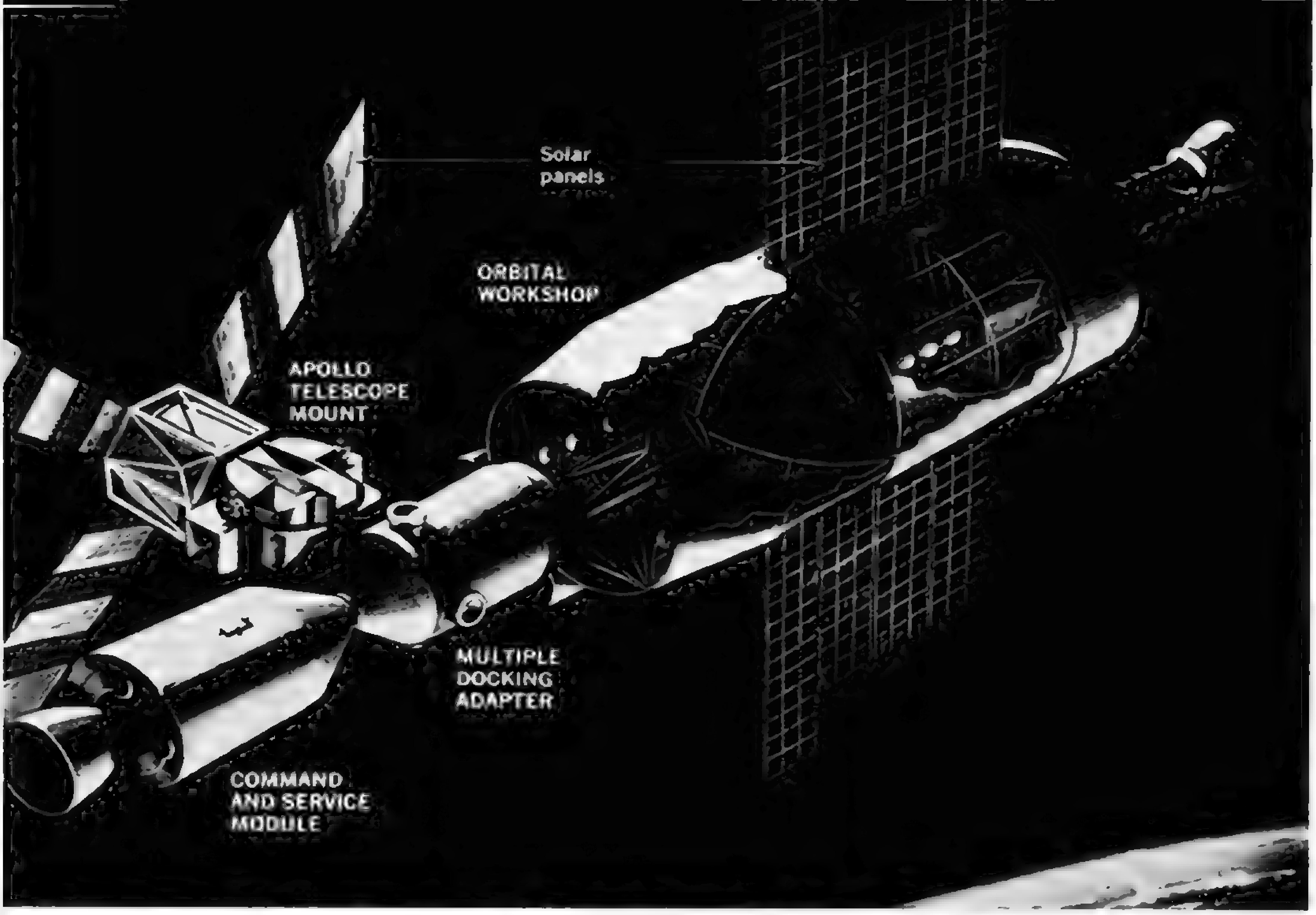
What it will look like may be seen from a full-scale mockup at NASA's Marshall Space Flight Center, which was assigned the task of designing and building the Apollo Telescope Mount. Overall it is about 22 feet high and nearly 20 feet in diameter, not counting four extensible solar panels that unfold to much greater span to provide electric power.

How sun will look to X-ray telescope is shown by rocket-borne camera's photo of solar disk by X rays it emits. ATM will get higher-resolution views.



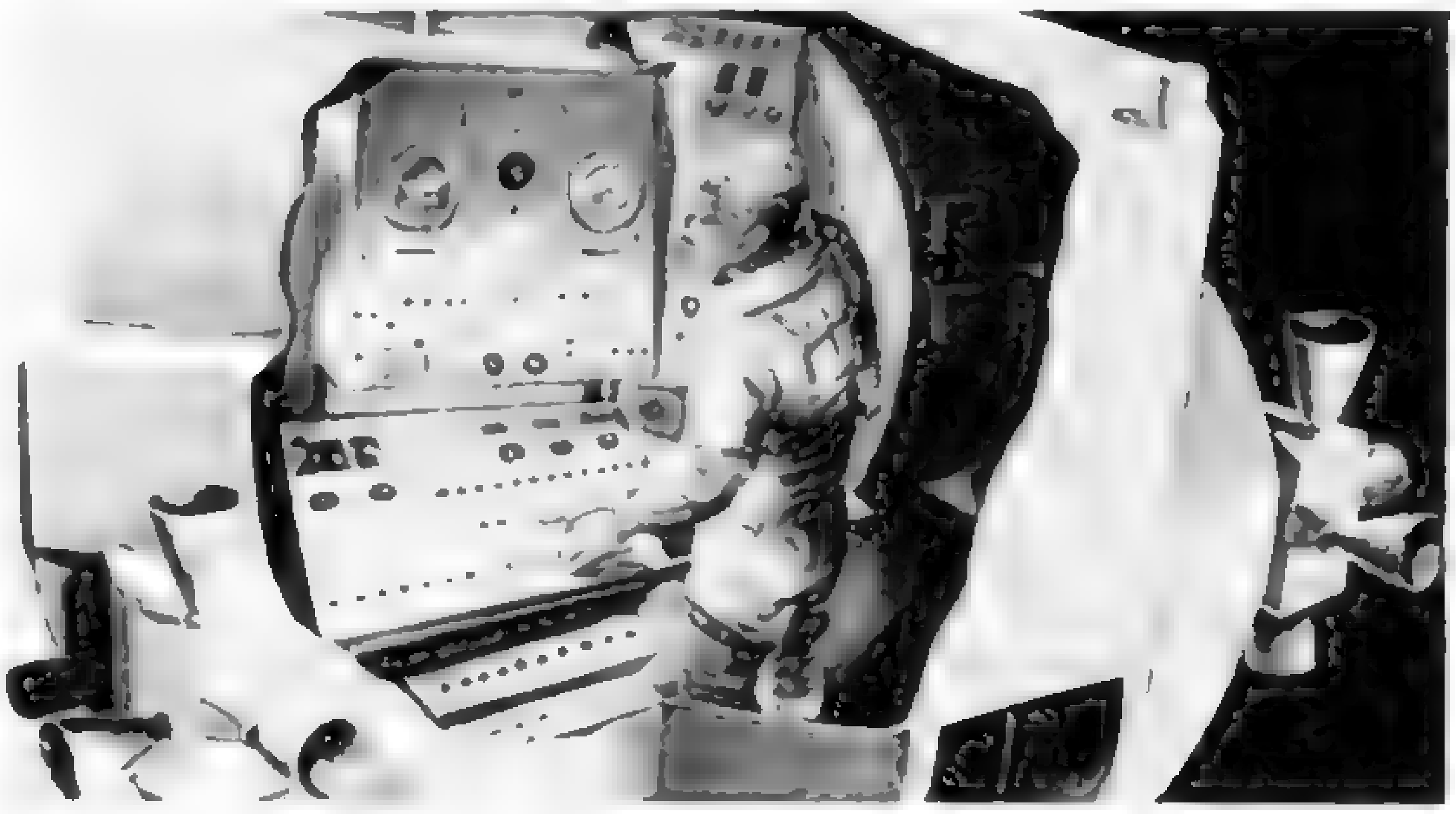
A cabin for the observers, which forms a major part of the spacecraft, provides a control console and TV-like display screens that will aid in aiming the telescopes and other instruments. These will be housed in a telescope tube, 11 feet long and nearly seven feet in diameter which can be pointed precisely at a chosen target.

The cabin of the ATM will be adapted from a two-man spacecraft, thoroughly



ATM observatory, with windmill-like solar panels, is pictured operating in orbit. To provide living quarters for observatory crew's stay of up to 56 days in space, ATM is docked to Orbital Workshop—as is the CSM that will bring men and films back to earth.

Full-scale mockup shows 22-foot-high observatory, with one of its solar panels partly extended. Upper part is observers' cabin; telescope tube is below. Domes seen amidships cover gyros for aiming.



Control console of manned observatory enables one observer to operate its instruments. Restraining straps (not shown) will anchor him in zero gravity.

gineered for the rigors of space, that already have. This is the Apollo nar Module's ascent stage—the vehicle it will serve, after two Apollo astronuts have landed on the moon, to return em from the lunar surface to the moon-biting Command and Service Module SM) for their homeward journey to rth. It will provide, equally well, the st requisite of the ATM—a habitable ucture in space for the astronomers' rking quarters.

Thus the ATM will consist essentially a Lunar Module ascent stage, minus the rocket engine needed for the lunar mission; and the telescope tube, projecting from where the engine and the descent stage would have been.

An eight-week observing mission. The first astronaut-astronomers are to remain in orbit up to 56 days. To provide enough living space for so extended a stay, the scheme is to dock the ATM to an Orbital Workshop—a spent Saturn S-IVB rocket stage, 58 feet long and about 22 feet in diameter. This large-scale space shelter will have been fitted with living quarters,

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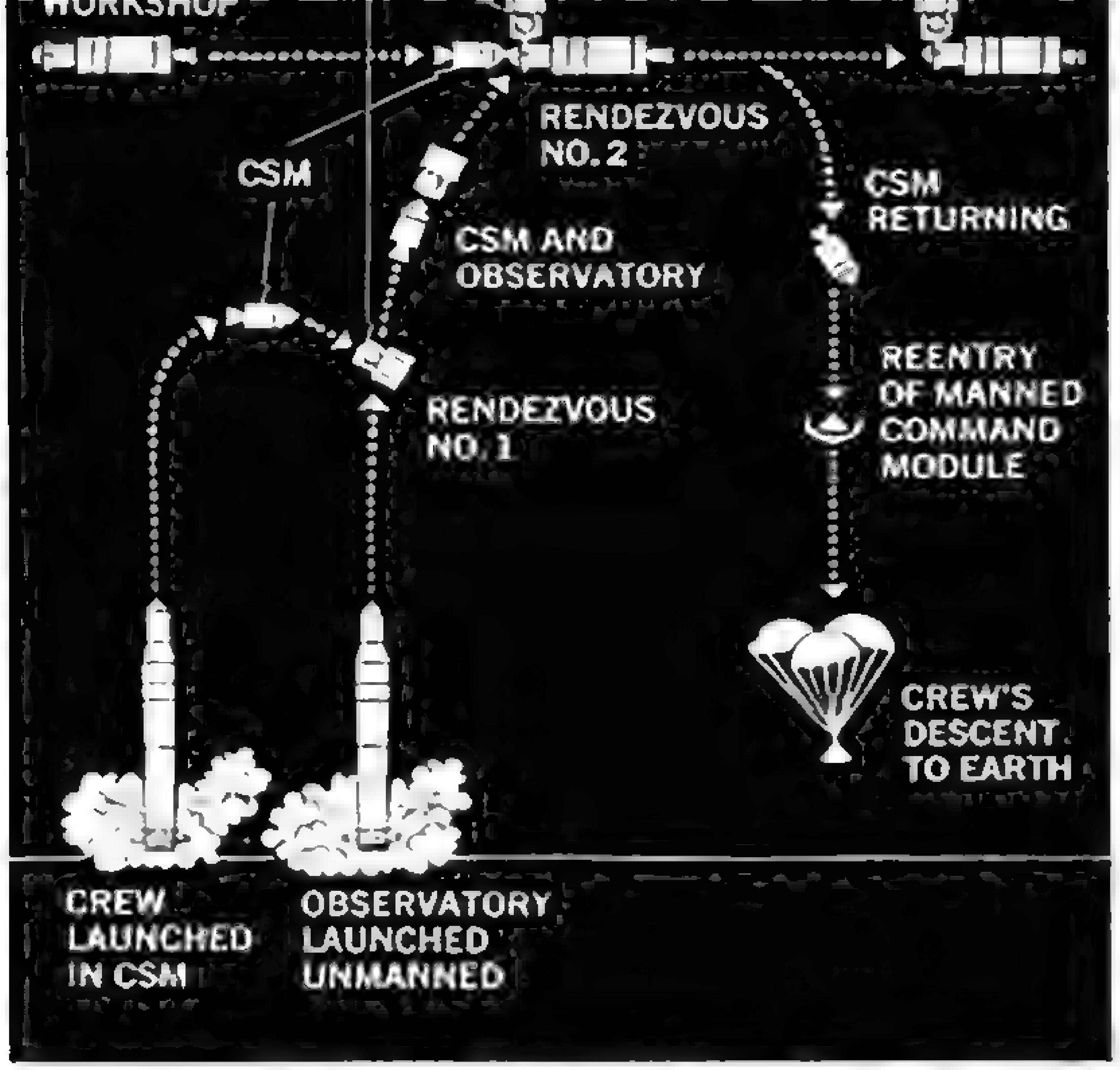

Flight plan to put ATM and observers in space goes from double launch to docking with Orbital Workshop, as pictured schematically. At mission's end, men descend in CSM, leaving ATM in orbit.

inhabited for space experiments, and then left circling at high 260-mile altitude by a previous three-man mission lasting up to four weeks.

The ATM flight plan. A double launch will put the ATM and its crew aloft:

First an Apollo Command and Service Module will be boosted by an Uprated Saturn I rocket into a low parking orbit. It will carry a crew of three—the two ATM astronomers, and a third astronaut who will have other space duties. Shortly afterward, another Uprated Saturn I will launch the ATM, unmanned, into a higher parking orbit.

The manned CSM will then rendezvous and dock with the ATM; and the joined craft will ascend to another rendezvous-and-docking, with the Orbital Workshop. The CSM and ATM will be docked separately to a multiple docking adapter, designed to accommodate a variety of space vehicles, at one end of the Saturn stage. Thus linked, the cluster will amount to an embryonic space station.

At the end of their mission the two astronomers will gather up their precious films and data and, joined by the third astronaut, will board the CSM to return to earth. They will leave the ATM attached to the circling Orbital Workshop, for use by later missions.

Earthbound observers can view the sky only by the kinds of radiation that filter through the "dirty basement window" o the earth's atmosphere—consisting almos entirely of visible light and radio wave: Above the atmosphere, in contrast, th orbiting ATM's astronomers will observ the full splendor of the whole gamut c radiation from the sun.

So it should be no surprise that th ATM will have exotic astronomical ir struments—most of them quite differer from those used on earth and thus unfa miliar to laymen. Special telescopes wi view the sun by extreme ultraviolet ligh and form a picture of its disk by its ow X rays. Such studies are of far mor than academic interest, since they hav decidedly practical aspects. From earl studies with rocket-borne instrument: for example, came the discovery tha monitoring solar flares' X rays can war of short-wave radio fadeouts on earth.

A Solar Physics subcommittee c NASA's Office of Space Sciences and Ap plications has selected these five sets c instruments for the first ATM:

There will be an X-ray telescope, fu nished by NASA's Goddard Space Fligh Center; an X-ray spectrographic tel scope, from American Science and Eng neering; two ultraviolet spectrometer from Harvard College Observatory; tw ultraviolet spectrographs, from the Nava Research Laboratory; and a white-ligh coronograph, from the High Altitude Ol servatory. This last instrument will ol serve the solar corona out to five to 1 solar radii—at which distance its ligl becomes so faint, only a billionth a

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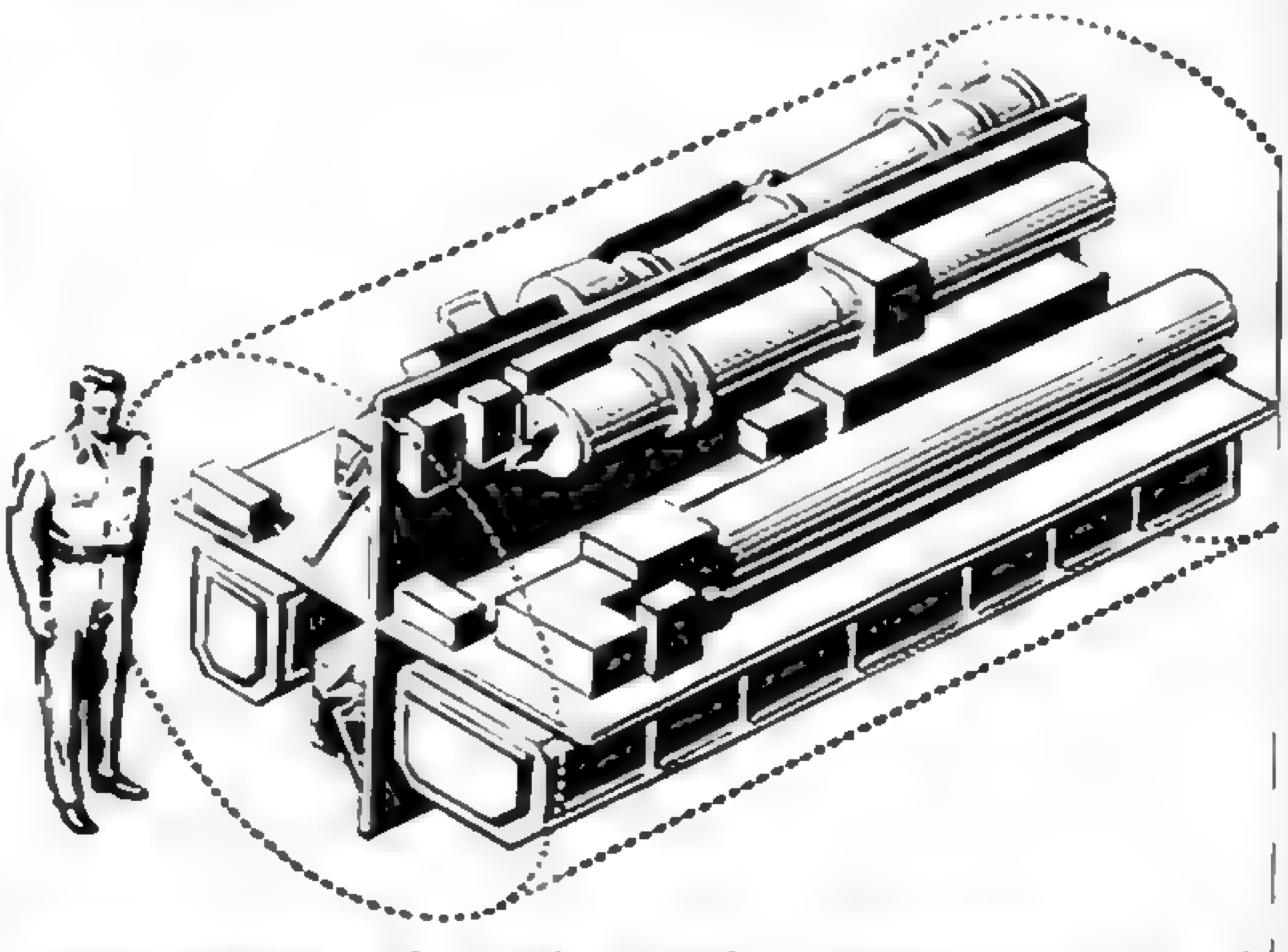

Instruments of ATM, within telescope tube (o lined), are on gimbal-mounted cruciform s that can be aimed independently of spacecraft fine control. Figure of man shows comparative s

Manned Observatory in Space

[*Continued from page 100*]

bright as the sun's surface, that it can be seen only from above the earth's light-scattering atmosphere.

How telescopes are aimed. Ingenious mechanical devices will compensate for the ATM's disadvantage compared to an earth observatory—lack of a rock-steady base for mounting and aiming telescopes.

Three 425-pound gyrowheels called Control Moment Gyros enable the observers to slue the whole spacecraft around, to aim the telescope tube at the sun. This orientation also permits the solar cells to extract maximum power from the sun's broadside rays.

A further refinement of aim is required, however, to counter the effects of elastic and thermal distortion of the ATM's structure, and of the movements of the astronauts within it. Therefore the ATM's instruments are mounted on a cruciform spar that is suspended in a separate gimbal system, for fine control. Electric motors, governed by a sophisticated sun-oriented fine-pointing system, rotate the mount around the two gimbal axes and also its longitudinal axis.

The spar and the instruments can thus be trained and kept pointed at any spot on the sun's half-degree-of-arc disk with an accuracy of 2½ seconds of arc—1/720 of the sun's diameter.

While there will be room in the cabin for two observers sitting side by side, it is expected that one observer will be able to aim and operate the array of instruments. This should enable the two astronomers to spell each other at observing tasks. The one on duty will need to be fresh and alert—for the birth of a solar flare occurs within minutes, and there may be only a few chances to detect and record such an event. Films brought back to earth will picture solar happenings with a quality of resolution far surpassing TV-like transmissions from unmanned satellites.

The first Apollo Telescope Mount, for observations of the sun, will be only a beginning. Already studies are under way for an advanced version of an orbital telescope mount that will permit astrophysical observations of stars and galaxies, dim in comparison with the bright face of the sun.

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Test Report on the Mustang, Camaro, Barracuda, Javelin

New PS Stereo Test Record

"Inner Space" Rehearsals fo

By DR. WERNHER VON BRAUN
Director of NASA's George C. Marshall Space Flight Center, Huntsville, A

Underwater trials are helping us pl the most ambitious tasks ever la out for our astronauts in orbit.

Coming space-flight missions i NASA's Apollo Applications Progra call for more complex activities und weightless conditions than anything ev attempted in the Gemini program. A tronauts will have to move equipme around and operate elaborate apparat in scientific and technical experiment They will live and work together in first-generation space station consisti of units brought together by rendezvo and docking in orbit. They will have emerge from their pressurized home o casionally—to replace a film cassette, just to fix something.

Engineers preparing these new m sions, in close cooperation with the

Dr. von Braun dons lead-weighted spacesuit (r to try out Neutral Buoyancy Tank—and feels heavy as if on planet Jupiter, before he enters ter. Submerged (below), he maneuvers in full-s mockup of a portion of Orbital Workshop—a "li room" in space—with a scuba diver close beh

To plan and practice coming tasks in orbit, our astronauts are simulating zero gravity under water—and the distinguished author, trying it for himself, tells here what it's like

Outer Space Adventures!

Underwater trials test foot and hand holds of a floor grid for Orbital Workshop. For safety, two scuba divers keep eye on spacesuited test subject.

tronauts who will fly them, must see that every piece of equipment is designed to suit the conditions of its use; that a mission's plan gives the astronauts ample time for what they are to do; and that they do not overexert themselves to perform their tasks.

Aircraft flights through "ballistic parabolas" have long been used to study human-engineering problems under zero gravity, and will continue to be tremendously useful. But weightlessness during ballistic aircraft flights is limited to less than a minute—too short for many of the complex tasks planned for the Apollo Applications Program.

All tasks requiring more time are therefore being studied in underwater tests—an idea pioneered by the astronauts themselves. Astronaut M. Scott Carpenter, the second American to orbit the earth, first pointed out the great potential of this way to study human-factors problems under zero gravity. Astronaut Eugene A. Cernan first tried it in a spacesuit. And Astronaut Edwin E. ("Buzz") Aldrin Jr., who rehearsed in a swimming pool for his successful space rigger's feats outside the orbiting Gemini 12 spacecraft, gave the final proof that underwater time, work, and motion studies in "inner space" really paid off handsomely in outer space.

Test tanks for space centers. Underwater simulation facilities, elaborate but relatively inexpensive, have been set up at NASA's Manned Spacecraft Center in Houston and its Marshall Space Flight Center in Huntsville. A test subject wears a standard spacesuit, weighted down to give him neutral buoyancy when he submerges in a tank of water.

He works on a full-scale mockup of a particular orbital installation, or a part of it, also submerged in the tank. Examples of what the mockup may represent are given by the three most important orbital-flight missions under the Apollo Applications Program:

- An Orbital Workshop, adapted from an S-IVB rocket stage, to study long-term habitability of an orbital "living room" and to conduct biological, physical, and technical studies under zero gravity.
- The Apollo Telescope Mount, an observatory with astronaut-operated instruments to study the sun, which I described last month in PS.
- A manned satellite, carrying an astronaut-operated array of remote sensors and multi-spectral cameras, to study advanced earth-resources survey methods.

To reduce water resistance in narrow passages, the mockup is an open-grid structure that permits water to pass freely through its walls. The upper side of a mockup has escape hatches that, pushed open from beneath, give free access to

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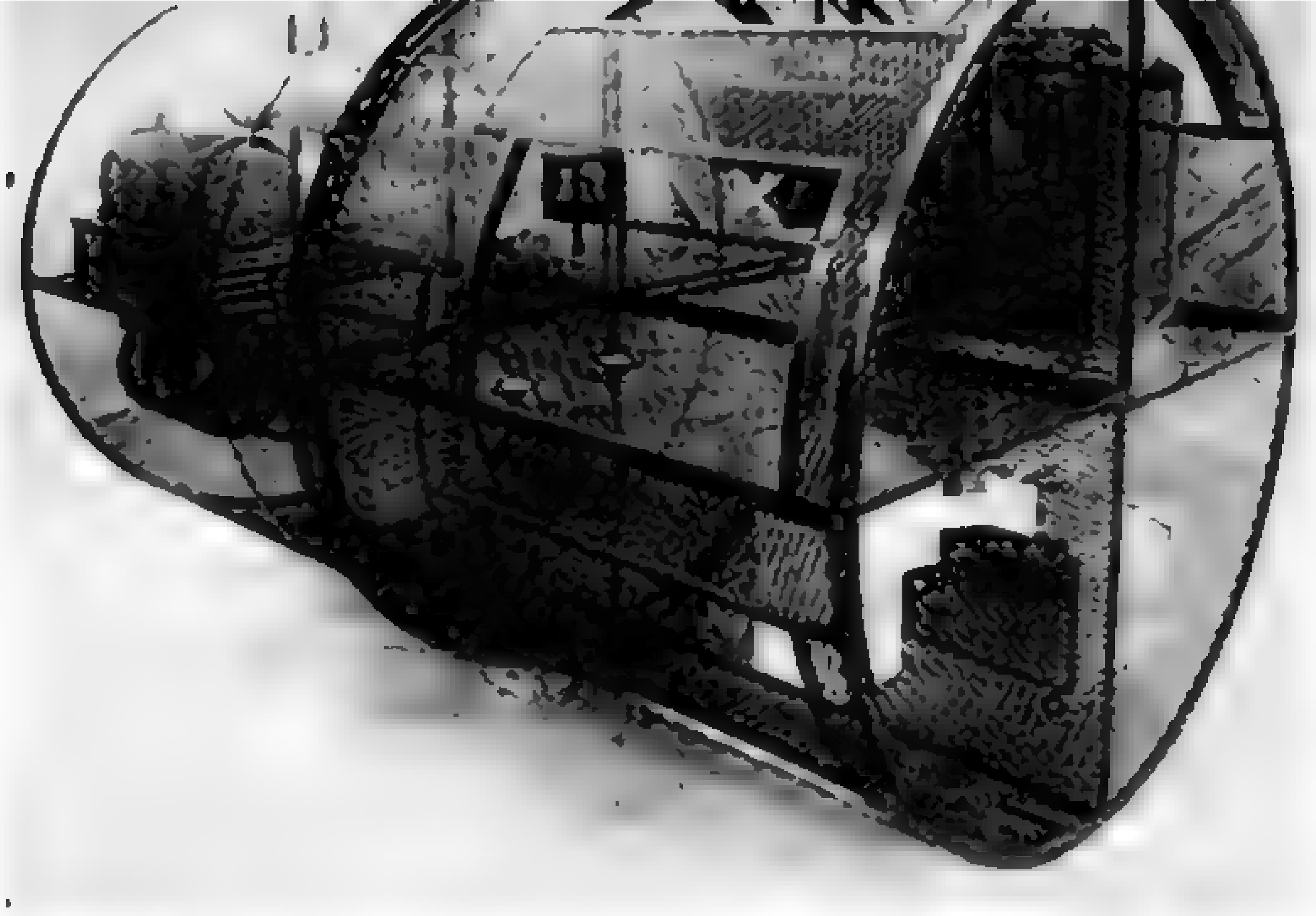

Open-grid walls of mockups keep subject's movements from being hindered by water resistance. This seven-foot-diameter mockup is of telescope tube for the projected Apollo Telescope Mount.

the water's surface in an emergency.

Trying it out. To familiarize myself with some of the astronauts' tasks and get a feel for their difficulties, I recently spent about an hour in the Neutral Buoyancy Tank at Marshall. I tried my hand at relatively simple jobs, such as placing a cover over a vent outlet, that are involved in "activating" the Orbital Workshop (which, prior to human occupancy, will have served as a hydrogen tank).

Before donning the pressurized spacesuit, I was wired up so that an outside observer could monitor my heartbeat and breathing cycle. This, I learned, was not only a safety measure against possible equipment failure or overexertion. It also provided a direct measure of my physical effort to perform a given task.

Effort data play a key part in the flight mission's ultimate "time-lining"—an important new word in space lingo that you may want to remember. It means working out a timetable for preparing and executing each task, for rest periods in between, and so on. With unrealistic time-lining, a space mission will either waste costly orbital man-hours for lack of enough to do—or it will hopelessly slip behind schedule, and many experiments prepared and carried into orbit at great expense will remain undone. Realistic time-lining demands the best data available.

After I was zipped up in the spacesuit and topped by the space helmet, a lead-weighted belt was thrown over my shoulders, and lead-weighted straps were fastened to my ankles. As I got up from my dress-up chair, I felt as if I had landed on the 2½-*g* surface of the planet Jupiter. But the load lightened when I entered the tank, where I first stood on a platform that kept me shoulder-deep in the water.

Now the pressurization of the suit began. They had strapped a dual pressure gauge to my wrist. The test controller, whose voice I heard over the helmet earphones, asked me to call out the suit pressure through my helmet mike. At a suit overpressure of 3.5 pounds per square inch, I was ready for underwater action.

Two scuba divers, who for safety always stay close to a test subject, gently inched me off the platform. They rotated me in a horizontal position, submerged and free-floating, to make sure I was properly weighted down to neutral buoyancy. I was. (They must have gotten my exact vital statistics from the Center doctor—or a fine retrim would undoubtedly have been necessary.)

My awkward attempts to perform the assigned tasks must have been as amusing to onlookers, below and above the waterline, as they were educational to me.

I was particularly impressed by the "straitjacket" effect our spacesuits still have. It takes physical force to bend your arm, because the internal pressure of your spacesuit wants your arm to be straight. The pressure also pushes your arm up around the shoulder joint, and it takes a certain effort to bring it down to your ribs.

A wrestle with a valve cap. One of my tasks was to push a hubcap-size cover over a valve, and secure it by a turn to the right—just as you would tighten the cap of your car's gas tank. As I tried to push and twist the cap into place, the reaction force turned me around instead. I anchored myself, with one hand, to a handhold provided near the work station—but found it awfully difficult to do the pushing and the turning with the other hand alone. After a minute of real hard physical effort, I was panting heavily and had to rest a bit.

Undoubtedly a few more hours of practicing this particular task would have enabled me to lick it. But I decided right then and there that the designers of that darn cap might as well take a course in basic physics, or try it in the

[*Continued on page 208*]

"Inner Space" Rehearsals

[*Continued from page* 108]

tank for themselves—and come up with a design better suited for zero-gravity operations in a spacesuit.

With scuba gear, it's another story. After exposing all my clumsiness in the spacesuit test, I tried performing the identical tasks in swimming trunks and scuba gear. The job in the spacesuit had made me perspire so profusely that I really longed for a refreshing swim—for physical contact with the water from which the spacesuit had separated me. And now I was in a familiar element.

I have been an active scuba diver since 1955, when the Sons of the Beaches of Los Angeles introduced me to this most fabulous of all sports. My thrilling experiences have included an encounter with two sharks, the spearing of a six-foot moray eel (which some scuba divers would respect more than a shark), and, at the invitation of Ed Link, free-diving from his research submarine Deep Diver while it lay at the sea bottom on the Continental Shelf off Grand Bahama Island.

The space rigger's tasks that were so difficult in a pressurized spacesuit turned out to be a cinch in swimming trunks and scuba gear. There was no spacesuit pressure to fight as I moved my limbs. My flippered feet gave all the maneuverability I wanted.

But, of course, kicking your feet won't get you anywhere in an air-filled environment, let alone an airless one! It is the first thing a skin diver has to unlearn when he turns to neutral-buoyancy work, for it would lead to wrong results.

What tank trials have shown. Underwater tests have already taught us valuable lessons. We have found out what can and cannot reasonably be expected from an astronaut under zero gravity; how much time and effort it takes; where foot and hand holds should be placed; how toggle switches should be reconfigured for easy operation; what corners should be padded, so a man won't get hung up or tear a hole in his suit. Most importantly, we have learned that whatever zero-gravity work can be done in shirtsleeves is many times simpler than the same work in a pressurized spacesuit that "fights back."

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Bigges

By DR. WERNHER
VON BRAUN

Director of NASA's
George C. Marshall
Space Flight Center,
Huntsville, Ala.

The leader of the Saturn team reveals the story behind the success of our first Saturn V-Apollo—an "all-up" gamble that won, to short-cut the way to a manned lunar landing

Within a few weeks our second Sat urn V rocket is due to put an Apoll spacecraft through new flight tests. Fol lowing the unmanned trial will come a least two manned Apollo flights thi year, including Saturn V's first man carrying mission.

What has cleared the way and i speeding these plans is the striking suc cess of the Apollo 4 mission—the maide flight of our giant Saturn V rocket.

The first Saturn V, with the fourt Apollo spacecraft in its nose, roared o its launch pad at NASA's Kenned Space Center at seven a.m. last Novem ber 9. Eight hours and 41 minutes late the Apollo Command Module gentl parachuted into the Pacific in sight o its recovery ship, the carrier USS Ben nington—its heat shield having passe the fiery test of a 25,000-m.p.h. reentr simulating a return from the moon.

It was the most difficult mission eve attempted in our space program—i terms of size, power, weight, cost, lack o precedent. Some news commentator

Up goes Saturn V, with Apollo spacecraft in nos on its spectacularly successful maiden flight. Giar 364-foot-high rocket—the crowning achievement c Dr. von Braun and his Saturn team, though his art cle modestly omits due credit to him—demonstrate its might by thrusting 140 tons into earth orbi

Rocket's Flawless Flight Speeds Moon Plans

even called it the most ambitious technological task ever undertaken by man.

Mission went perfectly. From telemetered data, there seemed at first to have been minor hitches—a second-stage engine quitting prematurely, a balky third-stage vent valve. Now we know these were false alarms, from gauges that played no active part in the mission. The flight was flawless.

Its success was a personal triumph for NASA's Associate Administrator for Manned Space Flight, Dr. George E. Mueller. It was he who, in the face of a more cautious and conservative attitude on the part of his closest associates (including myself), staunchly upheld the "all-up" testing concept. That meant trying out all three stages of Saturn V at once—and the Apollo spacecraft, too.

Customarily, flight-testing a new space vehicle begins with mockup hardware instead of live upper stages and a live spacecraft—and ultimate missions come only after success with simpler ones. True, the all-up concept has been tried for some military missile systems. But even the most complex, the Minuteman, was a humble firecracker compared with Saturn V-Apollo. Except for a Lunar Module, which was simulated, the Apollo 4 flight carried everything required for a manned flight to the moon.

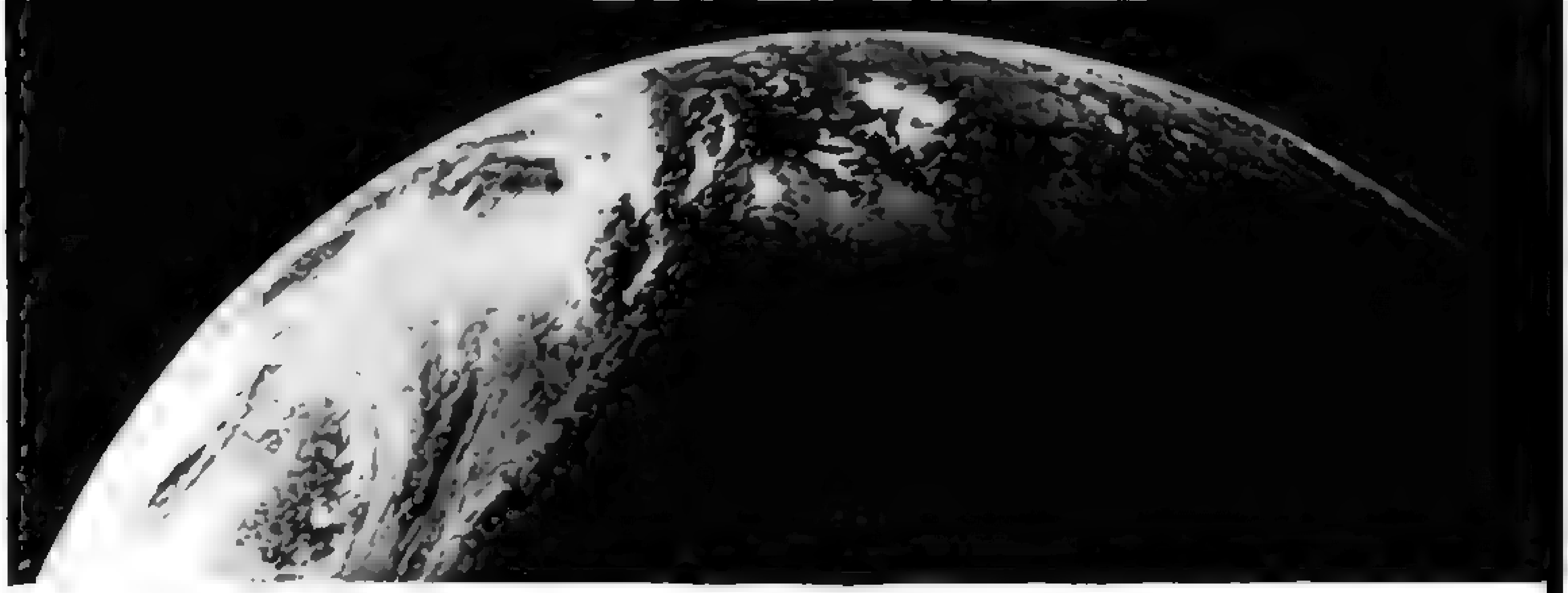
What was the reason for Apollo 4's complete success? It would be unmindful of Providence for me to say that "a little bit of luck" had nothing to do with it. And apparently we had very competent contractors. But you cannot rely on luck or contractors' competence alone in dealing with hundreds of thousands of parts, thousands of vendors, hundreds of subcontractors, and 20-odd prime contractors for flight hardware and vital ground-support items.

The scheme behind Apollo 4's success. Only one out of 20 men working on the Apollo program is on the NASA payroll, but overall responsibility clearly rests with NASA. Having established a sound concept of how to go to the moon, and defined the program's needs, NASA had to set up a system of management and program review to see that hardware items would work, that the taxpayer got his money's worth, and that efforts went according to schedule and master plan.

On the Washington level the Apollo program is directed by Maj. Gen. Samuel C. Phillips, an Air Force officer on temporary assignment to NASA with an impressive record as manager of complex new weapons systems. An Apollo Program

Continued

Launching Saturn V took this array of men and equipment, pictured during actual countdown, in firing room 3½ miles from pad. Liftoff was exactly one second behind prescheduled launch time.

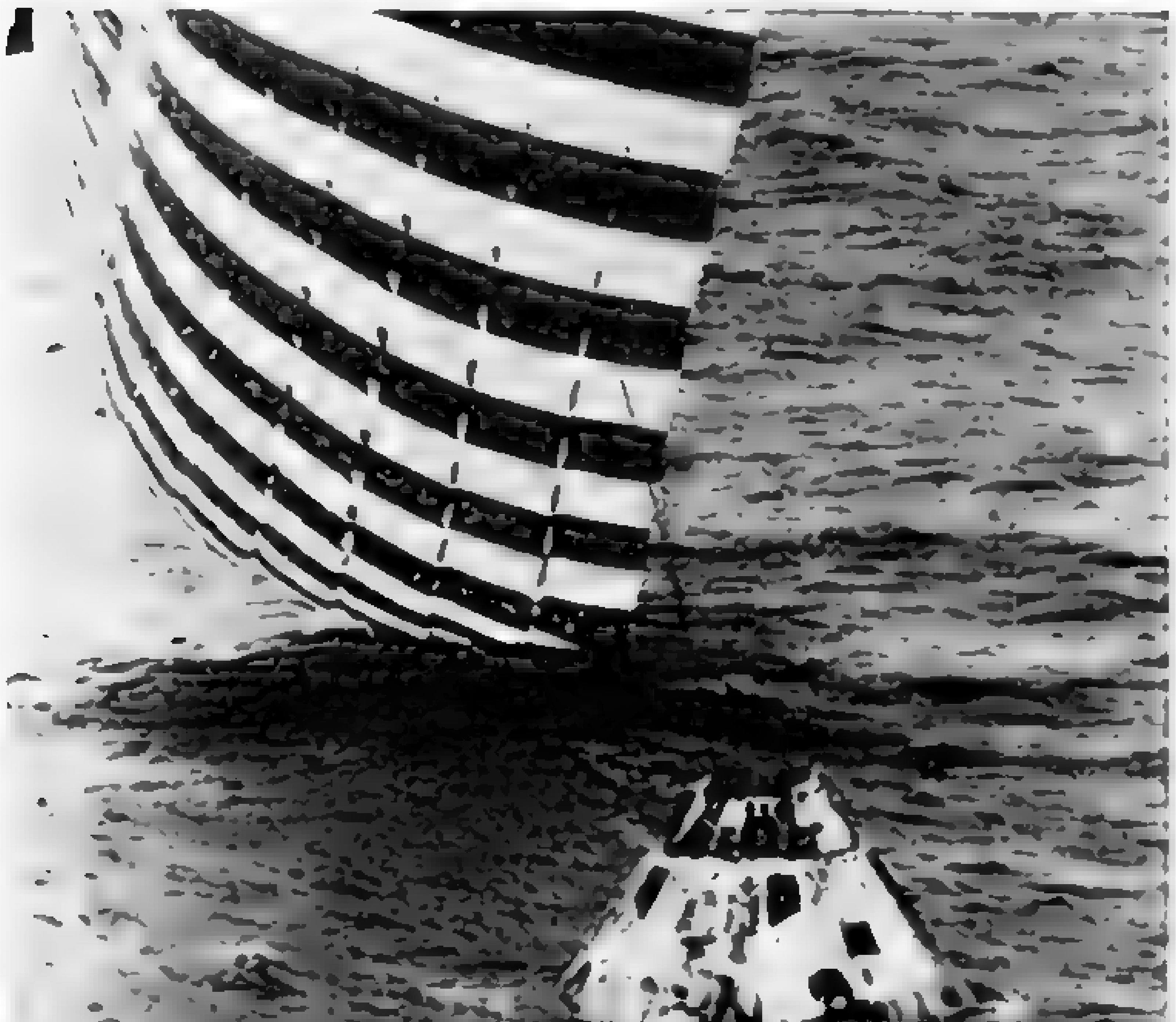


Earth looked like this to camera in Apollo spacecraft as it climbed from Saturn V orbit to 11,000-mile height, for start of power dive to test heat shield in fiery reentry at 25,000-m.p.h. speed of a return from moon.

Office at each of the three Manned Space Flight Centers—at Houston for the Apollo spacecraft, at Huntsville for the Saturn vehicle, at Cape Kennedy for launch operations—receives from Gen. Phillips its directives, guidelines, and resources. In the last five years these program offices, ably supported by the centers' research scientists and development engineers, burned tons of midnight oil over the program's endless details.

In monthly reviews before the Manned Space Flight Management Council—made up of Dr. Mueller, his two deputies, and the three Manned Space Flight Center directors—the Apollo Program Director and Program Offices in the field present accurate accounts on the status of money, manpower, timetables, critical items, and necessary changes. The reviews eye these areas, particularly:

Components. Every item—a structural part, a valve, a relay—has to prove able to withstand its predicted environment: high or low temperature, violent vibrations, or ambient vacuum in outer space



In flight's bull's-eye finish, Apollo plops into sea in sight of recovery ship 275 miles off Midway Island. It passed heat-shield test, and all its contents—including its earth-photo film—were found intact.

Systems. Parts must work as a team A space vehicle placing a spacecraft o a ship's bow in the far Pacific can b compared to a postman delivering a package. An instruction is placed in a memory—the postman's, or that of Apollo's guidance computer. Energy is expended—by the postman's leg muscles or Saturn V's engines. In between, a complex network's functions are vital to success. Like a postman, Saturn V needs a sense of balance (its autopilot) and a muscle-controlling nervous system (its electric network) to get where it is going

Tests of systems, therefore, complement tests of components. And a study showing a system at the mercy of a single part's failure may lead to a design change or provision of back-up elements

Manufacture. Testing finished items is not enough. Inspection during their manufacture avoids painful discoveries too late, when rejecting a costly product is the only recourse. Continuous monitoring of makers' processes played a major part in the success of Apollo 4.

Engineering changes. Tests produce directives to makers to rectify deficiencies Meanwhile, components arriving at assembly plants may lack the changes Lest chaos result, the answer to keeping track of innumerable alterations has been found in "configuration control," using a multi-layered Change Board and a document-policing organization made up of both NASA and contractor personnel.

Thus, building a craft to carry men to the moon—challenging as it is to engineers and scientists—exhibits broad management aspects having little to do with engineering and even less with science

One of the best criteria of a competent management system is that it carefully follows up on every single action taken to make sure nothing has fallen through a crack. The success of Apollo 4 showed that nothing had.

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How Astronauts Learn Space-Flying on

To train spacemen before they start, ingenious simulators duplicate a single task or key events of a whole mission

By
DR. WERNHER VON BRAUN

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

Training with simulators, for astronauts and flight controllers, is the key to success in manned space flight.

You can learn to drive a car or fly an airplane in relative safety just by doing it often enough—first with an instructor at your side, and then by yourself. But an astronaut must be able to handle his spacecraft expertly the first time he flies it. The same skill is required of a flight controller, on the ground, who is in charge of directing and supporting a manned space-flight mission never attempted before.

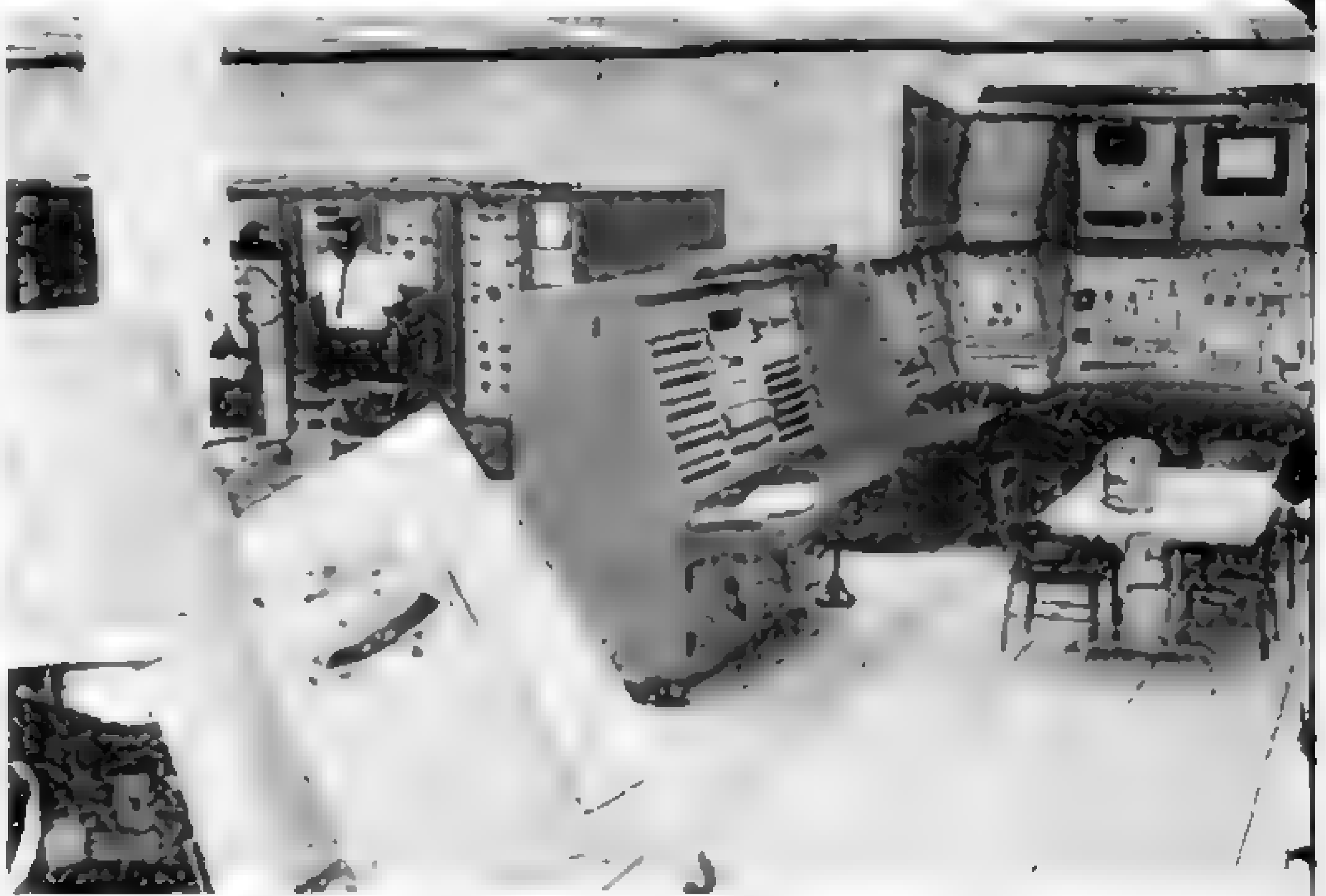
When it comes to a mission as complex as an Apollo flight to the moon and back, including a soft lunar landing, obviously no single simulator could suffice. It would be impossible to design one capable of duplicating the whole sequence of events for the three members of the flight crew—and for the flight controller on duty at the Mission Control Center, together with a battery of console operators and all the personnel manning the tracking and communications stations of a global network. Therefore flight and ground crews practice with a number of less-universal simulating devices, each covering one or several more-limited aspects of a mission.

These training devices range over a whole gamut from rather simple part-task trainers to highly complex integrated-mission simulators.

What part-task trainers do. An example of a part-task trainer is MSC-Houston's Gemini-Agena Docking Simulator (pictured on this article's third page). Gemini astronauts used it to study and practice their final latch-on maneuver with a target Agena spacecraft, after preliminary rendezvous brought them to a station-keeping position within a few hundred feet of the unmanned Agena.

(This Gemini technique is by no means something all in the past, it may be noted here. Six- to eight-man spacecraft are expected to become earth-to-orbit "ferries" serving our coming orbital space stations—and they will perform docking maneuvers like the ones pioneered with Gemini and Agena.)

In actual flight the Agena's control system would maintain a stable attitude



Gemini Mission Simulator at Houston is example of an integrated trainer that reproduces most of a space flight. Computers activate instruments and controls in the capsule (left foreground).

Earth

in space, but would not change Agena's unpowered orbital-flight path. The real-life Gemini spacecraft could be rotated by the astronauts with small joystick-controlled thrusters, in pitch and yaw. With a second control stick, it could also be linearly accelerated in fore-and-aft, up-and-down, and right-and-left directions.

Now, in the docking simulator, there were no thrusters at all. The Gemini capsule was mounted on gimbals so that it could be pitched up and down, and yawed right and left, by little electric servomotors that the joystick actuated.

The linear motions, under the command of the other control stick in the Gemini, were actually performed by the Agena instead. For the flight crew in the Gemini, this made no difference. As the two sticks were operated by the Command Pilot, both he and the right-seat pilot, looking through their respective windows, would see their own craft approaching the apparently motionless Agena—until the nose of their Gemini nudged into the docking cone for the final latch-up.

One-sixth-g simulator makes this subject, carrying out an experiment in an artificial lunar crater, as light as he would be on moon.

Another example of a part-task simulator, the 1/6-G Lunar Surface Trainer, trains pressure-suited Apollo astronauts to walk and perform tasks on the moon's surface. In essence the simulator consists of a gimbal suspension system equipped with a load-sensing strain gauge. The gauge actuates an electric motor that pulls on the suspension cable and cancels out five-sixths of the astronaut's weight, regardless of his position. He is then as light as he would be on the moon, where gravity's pull is only one-sixth as much as on earth.

Integrated trainers. At the other end of the range of simulators are integrated systems like the complex Gemini Mission Simulator in Houston (illustrated on the opposite page). They simulate as much of a space flight as possible, with the limitation that they do not imitate actual motions of the spacecraft.

This severe restriction means that important sensations felt by the crew, as in launch and reentry accelerations, are not simulated—and so must be studied as separate problems on centrifuges. Nevertheless, the integrated flight simulator ful-

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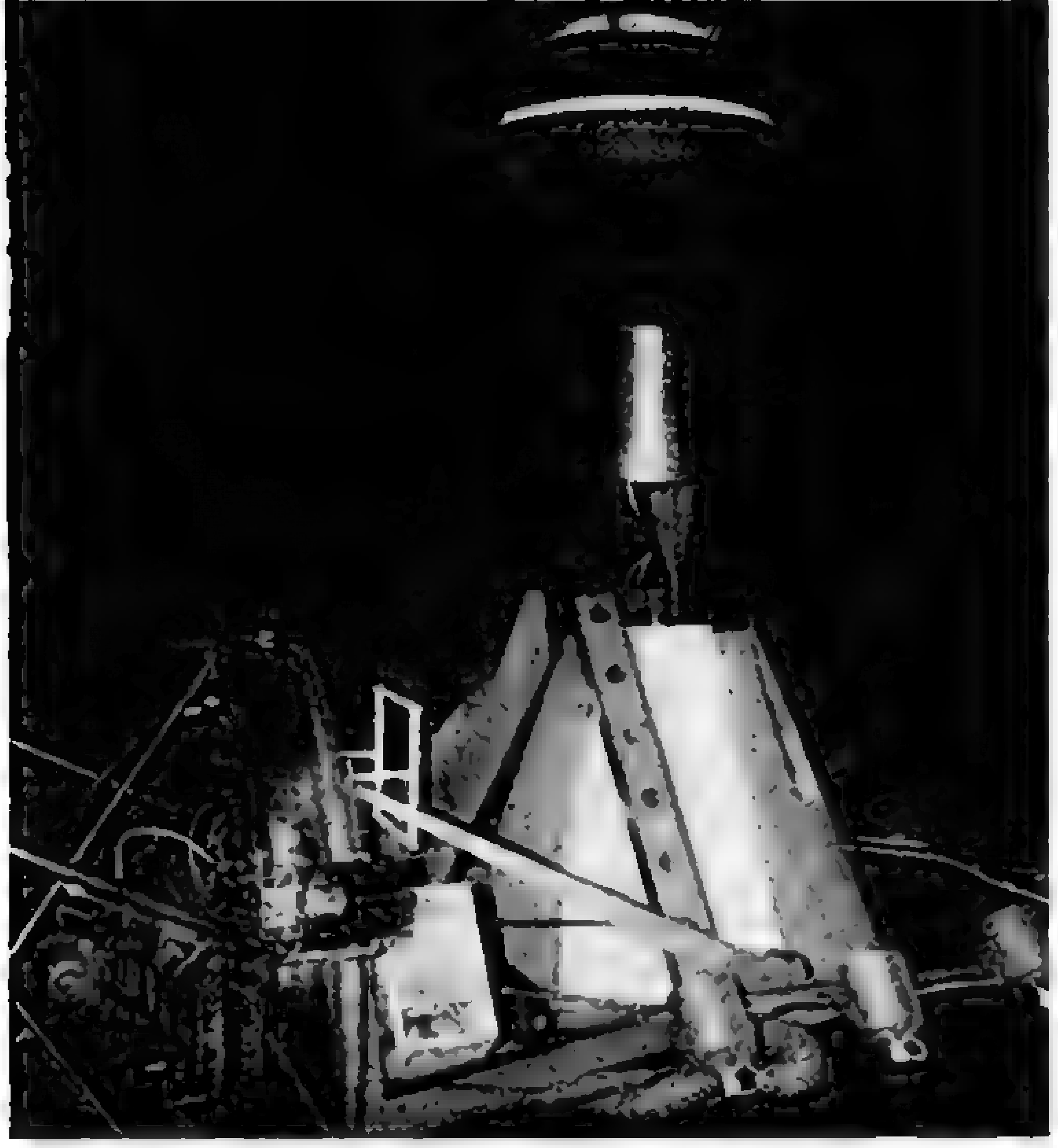

Docking simulator enabled Gemini astronauts to practice latching their orbiting vehicle to target Agena spacecraft after rendezvous. Future earth-to-orbit ferry spacecraft will make similar maneuvers.

fills many vital functions. Within a cabin duplicating that of the actual spacecraft, a flight crew can:

- Become familiar with the appearance of all instrument displays under conditions encountered in an actual flight.
- Become acquainted with out-of-the-window views. The crew will see the earth's rim or the moon through a visual-display system, driven by a computer, whose projectors cast TV-like displays on simulated windows of frosted glass.
- Learn to detect and correct the most likely system failures.
- Become familiar with the dynamic-response characteristics of their spacecraft—indicated both by out-of-the-window displays, and flight instruments—on either autopilot or manual control.
- Get a feel for overall timing.
- Practice tasks peculiar to a specific mission.

All instrument displays, switches, and controls are active—although computers determine what they show and do.

From an elaborate console, instructors can throw synthetic "troubles" into the operation of the simulated spacecraft systems. An objective of a typical training session is to observe how the flight crew deals with these system "failures," and with how much delay.

Integrated flight-mission simulators serve too as a vital part of a complete mission's dry run—including not only the flight crew, but also the vast ground organization supporting them.

Ground flight controllers, before taking part in such a dress rehearsal, must have had a thorough piecemeal-training program to become familiar with:

- All spacecraft systems and subsystems, and their functions. If trouble strikes in the far-away spacecraft, ground flight controllers must be able to analyze the problem quickly.
- Spacecraft procedures. They must know where switches are, and what can be concluded from certain cues—instrument readings, sights seen through windows.
- Their own Mission Control Center and all the remote sites supporting it.

In many phases of an actual space flight, neither the flight crew nor the ground crew have all the information or control necessary to carry out a successful mission. An interchange of information between the spacecraft and the ground is required, possibly with critical time allowances. Here lies the main significance of completely integrated flight-mission simulators. The integrated mission test, making full use of voice-radio interchanges between flight crew and ground flight controller, provides an extremely realistic simulation of the conditions during an actual flight.

The final dress rehearsal of a manned space flight, the Flight Mission Readiness Test, is conducted with the flight crew and the Flight Director at widely separated locations.

For many reasons the flight crew must move to the Florida launch site several weeks before their flight. A duplicate Flight Crew Trainer—the spacecraft portion of the integrated flight-mission simulator—is therefore set up at the Kennedy Space Center in Florida. The Flight Director and his ground controllers continue their functions at the Mission Control Center in Houston, Tex. Like an orchestra performing its last dress rehearsal the day before the Grand Opening, all the players in the intricate symphony of space flight are thus being sharpened until the countdown clock reads zero.

Astronauts' training has other sides. It would be wrong to conclude that the training of astronauts aims solely at cockpit

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Astronauts Learn Space-Flying on Earth

[*Continued from page 104*]

proficiency and smooth cooperation between flight and ground crews.

To understand the environment in which they must perform, and the hardware that helps them in their travels, astronauts must attend academic courses in the following fields: Astronomy, Physics of the Upper Atmosphere and Space, Bioastronautics, Rocket Propulsion Systems, Flight Mechanics, Aerodynamics, Computers, Guidance and Control, Space Navigation, Communications, Meteorology, Selenology (geology of the moon), and Environmental Control.

Besides this academic program, they must spend some of their time on activities such as launch-vehicle and spacecraft familiarization, mainly at manufacturers' plants; water, desert, and tropical survival training; and operational training, which includes such things as emerging from a spacecraft after a splash into rough seas, and acting in a flight mission as ground flight controller or as "Capcom," which stands for capsule communicator.

In addition, astronauts actively participate in many spacecraft-development and mission-planning meetings, where their simulator and flight experience is eagerly sought by engineers.

Aircraft are training aids. Finally, astronauts have to put in a substantial number of pilot hours in jet aircraft and helicopters—simply because these are the only known simulators that require a spaceman to react rapidly and accurately to stress-filled situations. As Donald K. ("Deke") Slayton, director of flight-crew operations at the Manned Spacecraft Center in Houston, puts it:

"An aircraft may not translate to a spacecraft directly, in terms of controls and displays, but it is the only unforgiving trainer we have." With a simulator, "If you goof you can shut it down, recycle the computer, and start over again. With fighter-type aircraft you can't quite get away with that."

Training for space flight is a busy undertaking. NASA's 2,000-hour training plan for Apollo astronauts, which is preceded by a six-month academic indoctrination, covers a period of 40 weeks and is based on a 51-hour work week.

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Weird metal-tired conveyance—a Mobility Test Vehicle—is piloted by Dr. von Braun above. It represents chassis of projected MOLAB—a Mobile Lunar Laboratory for long-distance travel on moon surface.

Moon-Exploring Vehicles Our

Red-hot motors and helicopter-like rocket gear will drive strange lunar vehicles now being designed

By DR. WERNHER VON BRAUN

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

Because of long lead times, vehicles for lunar-surface travel—on missions immediately following our first Apollo moon landing—are becoming of rapidly growing interest to NASA.

A stay of about 18 hours on the moon after the initial landing is now planned—enough to probe the lunar surface and collect soil samples near the landing site. So short a stay does not require devices to give astronauts mobility.

But the moon has a vast surface, with many interesting features far apart. Built into the Saturn V-Apollo system is provision for enough growth in capability to permit us to carry lunar vehicles to the moon, and to extend the time of astronauts' stay on the surface.

Driving and flying are the two feasible ways to travel on the moon. NASA has been conducting studies of both, in cooperation with private industry. Companies particularly involved include Lockheed, Bendix, Boeing, General Motors, Brown Engineering, Grumman, and Bell Aerospace Systems.

Surface vehicles. It has been clearly established that, on the moon, wheeled vehicles are superior to track-laying ones. Wheels require less power, are less subject to the temperature extremes between lunar day and night, and are easier to

Dr. von Braun, in driver's seat, grasps steering controls of Mobility Test Vehicle for a trial run.

Metal tires, needed on moon, are viewed by author (right). They yield to roll over uneven lunar soil.

Astronauts Will Drive and Fly

lubricate on the airless moon, where grease and oil would evaporate rapidly.

Metal tires, because of the extremes in soil temperature, must take the place of rubber ones. Each wheel will be driven by an individual electric motor. The four motors get their power from a hydrogen-oxygen fuel cell.

Much research and development has gone into these motors, for the environment in which they must perform is unique and harsh. There is no air to cool the armature and field coils. As a result, the entire motor is designed to operate at red-hot temperatures so it can radiate excess heat away, even during a hot lunar day. Ceramic materials replace organic insulation and potting compounds.

Dry self-lubricating bearings are used throughout the vehicle. Front-wheel steering is conventional, but the steering wheel has been replaced by two-stick steering, as in military tanks.

The first manned lunar-surface vehicle

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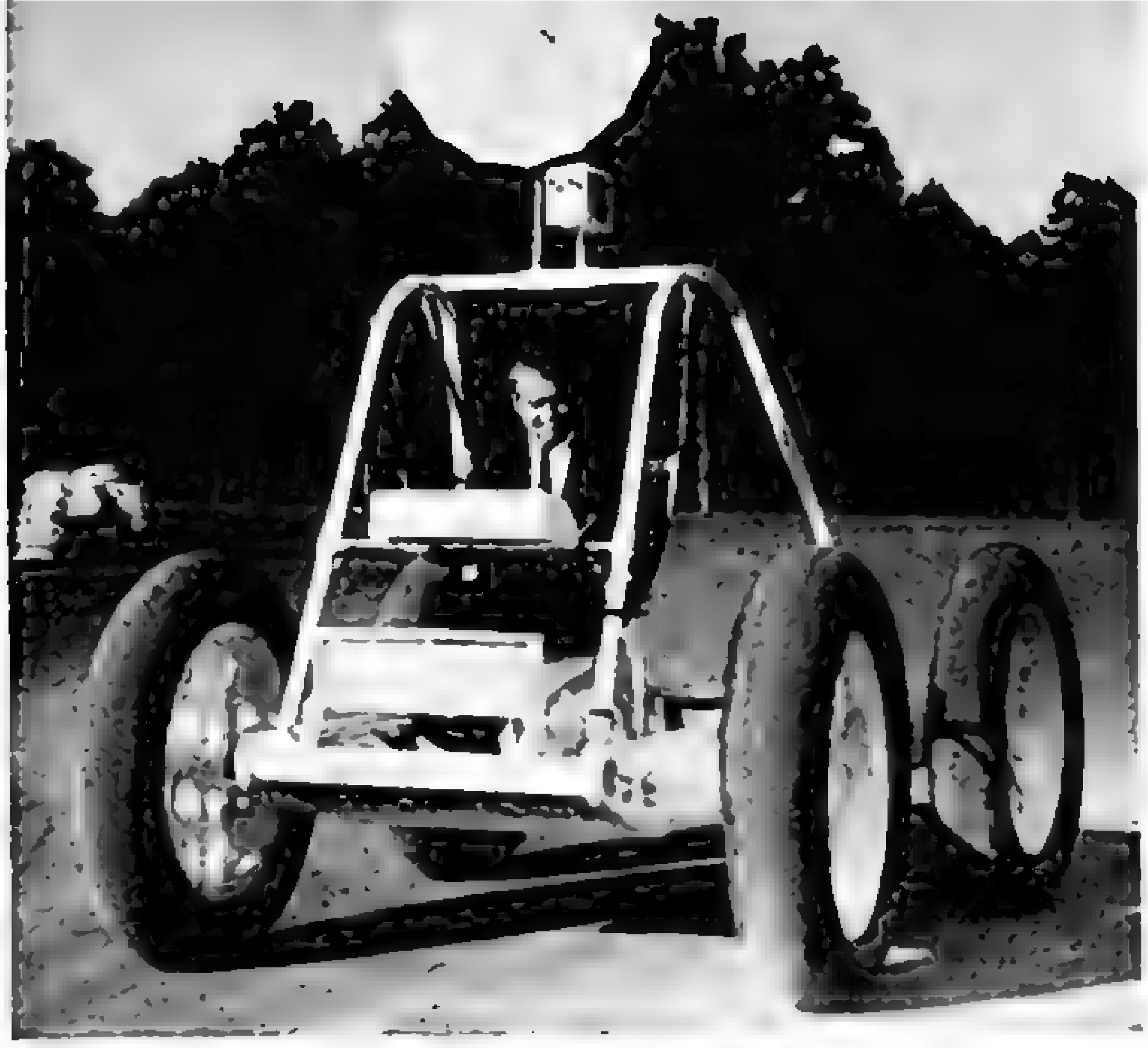
Flying lunar vehicles will probably look like this envisioned one-man craft (and a similar two-man version). Note large lifting thruster. An array of small thrusters provides joy-stick attitude control.



Mockup of open "lunar jeep" (LSSM) takes Dr. von Braun for ride on test track. Steering gear, and dish antenna atop frame, are suited to use on moon. (Battery power and rubber tires are for earth only.)

earmarked to be put into practical use is an open "lunar jeep" called the LSSM (Lunar Scientific Surface Module). It can accommodate either two space-suited men or a driver plus cargo. It has a bowed canopy to protect the astronauts and their vulnerable pressure suits in case the vehicle topples in treacherous soil.

A swivel-mounted dish on top of the canopy serves as a directional antenna for receiving and transmitting. The LSSM has about a 10-mile radius of action. It can be lowered to the lunar surface strapped to the side of an LM Shelter, a small structure designed to serve as the astronauts' base [PS, Nov. '66].

Trials of some of the LSSM's features have already been made with a drive-around mockup, powered by batteries, and pictured above. The mockup is designed for a less-hostile earth environment (as its rubber tires show).

The LSSM may be preceded by an unmanned roving vehicle of similar appearance. This could be carried to a soft landing on the moon by a Lunar Module, or by a separate medium-powered rocket such as an Atlas-Centaur, Titan-Centaur, or Saturn I-Centaur. A television camera mounted on the rover would transmit a moving picture to the screen of an armchair driver on earth, who would drive the vehicle around local obstacles on the moon by remote radio control.

Guiding a roving lunar vehicle from a driver's seat on earth is quite a trick, because of the time delay in response. It takes 1¼ seconds for the TV signal to go from moon to earth, and another 1¼ seconds for the radioed remote-control signals to travel back to the moon.

I had an opportunity recently to try it for myself on a simulator. It became clear to me that, on any but a very even and obstacle-free terrain, it should not be expected to be possible to drive the roving lunar vehicle safely at a speed exceeding 20 m.p.h.

An unmanned rover driven from the earth offers some substantial advantages. It can readily be exposed to hazards unacceptable for a manned vehicle. Thus it could be driven into rough areas and treacherous terrain. If we coordinate its land traverses with the exploratory activities of a group of astronauts, the rover could collect soil samples from inaccessible places and turn them over to the astronauts, who would bring them back to earth.

Communications problems. As long as we limit the rover's excursions to the visible side of the moon, it will be in uninterrupted line-of-sight radio contact with the earth. Due to the earth's rotation, direct communication with any one earth station is possible only as long as the moon is above that station's horizon. This restraint is entirely acceptable. All we have to do is stop the vehicle, when the moon sets below our station's horizon, and continue its travel after the moon has risen again. We could also quite easily provide a hookup for round-the-clock operation of the rover with the aid of some of the existing communications satellites.

Reliable communication between two moon sites poses a tricky problem. With the moon's small diameter, the local horizon is only a few miles away. Since the moon has neither an atmosphere nor an ionosphere, radio waves travel in straight lines, and refuse to follow the moon's curvature. Thus, even a small hill a mile away can completely obstruct radio communication with a lunar-surface vehicle a mile beyond that hill.

One way to overcome this problem is to use the earth (or a moon-orbiting satellite) as a radio relay. Another way, for a moon party that wants to communi-

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Moon-Exploring Vehicles for Astronauts

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cate with another, is to launch a moon-rated antenna-trailing Fourth-of-July rocket. It could serve as a radio relay while it was high enough to be in line of sight of both stations. The weak lunar gravitational field makes this method quite attractive, as the altitudes and flight times attainable even by small rockets are amazingly high.

A mobile lunar laboratory. After early exploration of limited areas on the moon, with the help of unmanned rovers and manned LSSMs, astronauts will want to launch major cross-country traverses over the face of the moon. Such traverses cannot well be made in open vehicles like the LSSM. They are going to require a large, sophisticated vehicle that we call a MOLAB, for Mobile Lunar Laboratory.

A MOLAB will have a pressurized cabin, which permits shirt-sleeve operations. It will contain facilities for sleeping, eating, and working.

The chassis for a MOLAB has been extensively studied at the Marshall Space Flight Center with the help of a trial version that we call the Mobility Test Vehicle. It is pictured in the photos at the beginning of this article.

Several companies have submitted detailed proposals for MOLABs of several hundred miles' range, but so far no hardware development along those lines has been approved and funded by NASA.

Flying vehicles. Lunar flying vehicles offer another approach to providing mobility for astronauts on the moon. It seems that they will not compete with wheeled vehicles—but, rather, will be a welcome complement to them. For, while a wheeled vehicle is best suited for transportation across relatively level ground, a flying one serves ideally to descend into a steep-walled crater or to fly up to a lofty peak.

Work on flying vehicles has been promoted particularly by Bell Aerospace Systems, maker of the highly successful Bell helicopters. All lunar flying vehicles utilize straight rocket propulsion for lift and forward movement. While a rocket providing enough lift for hovering would have a prohibitive fuel consumption in the strong gravitational field of the earth, it

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Moon-Exploring Vehicles for Astronauts

looks quite attractive on the moon with its feeble 1/6 *g*.

A man himself becomes rocket-propelled with Bell's famed strap-on "rocket belt" [PS, Dec., 1961]. To demonstrate their confidence in it, Bell had a rocket-powered man fly right over their factory and land at our feet. For people more sedately inclined, they had also rigged their controllable rocket propulsion to what they call a "flying chair," and gave us a stunning demonstration.

For lunar use, flying vehicles will probably take on an appearance like the version pictured on a preceding page. They can be flown in two fundamentally different modes, or in a mixture of the two:

One is the "helicopter mode." The downward component of the rocket's thrust cancels lunar gravity, and the horizontal component provides forward acceleration. The other is the "ballistic mode." To travel from one point to another on the moon, the flying vehicle builds up the necessary speed in an upward-slanting direction. Its ensuing free-flight trajectory carries it unpowered to its destination. Prior to impact, a retardation maneuver reduces its speed. For long distances, the ballistic mode takes less propellant and seems superior. Whether ballistic flights will be acceptable from the safety standpoint, only the future can tell.

No longer a faraway need. Current developments are hastening the day when lunar vehicles will be required. All the hardware required to carry our Apollo astronauts to the moon has now been flight-tested. The flawless flight of the first Saturn V rocket last November showed the soundness of its design. The equally perfect deep-space test of the first Lunar Module last January proved it, too, ready for action.

Several manned flights will now gather experience with all these elements—and study, separately, critical phases of the more-demanding lunar mission. Thus, the first lunar-landing crew will benefit from the lessons learned in these earlier partial missions. Then, with succeeding lunar flights, will come the vehicle-borne exploration of the moon described here. PS


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Spaceman Finds New Thrills

Our outer-space expert turns to inner space for a vacation of exciting scuba-diving adventures

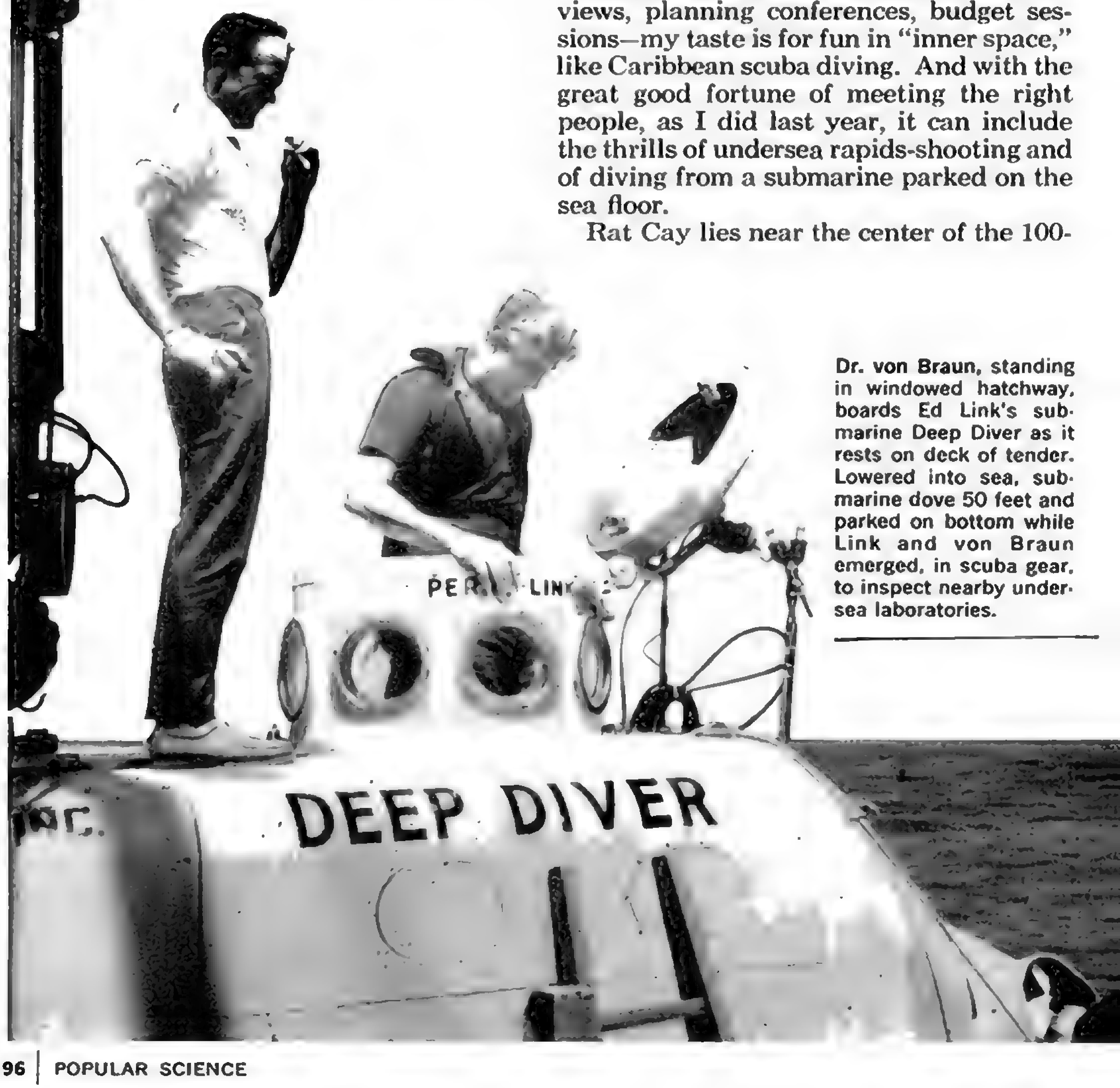
By DR. WERNHER VON BRAUN

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

Scudding past us was the sea bottom—so close that you could reach out and catch a handhold on a coral head, to make it stand still. On the warm water's surface, 30 feet or more above us, a Boston Whaler trailed us by our air bubbles. In scuba gear, we were enjoying a weird and exciting adventure—shooting the underwater rapids of the Caribbean, off Rat Cay in the Bahamas.

For a vacation from all those unglamorous but necessary activities that go into our spectacular space launches—design reviews, planning conferences, budget sessions—my taste is for fun in "inner space," like Caribbean scuba diving. And with the great good fortune of meeting the right people, as I did last year, it can include the thrills of undersea rapids-shooting and of diving from a submarine parked on the sea floor.

Rat Cay lies near the center of the 100-



Dr. von Braun, standing in windowed hatchway, boards Ed Link's submarine Deep Diver as it rests on deck of tender. Lowered into sea, submarine dove 50 feet and parked on bottom while Link and von Braun emerged, in scuba gear, to inspect nearby undersea laboratories.

Shooting Undersea Rapids

mile-long Exuma chain of several hundred islands in the Bahamas. This chain acts like a dam between the Atlantic to the east and the Caribbean to the west, and the narrow passages between the islands are like spillways of the dam. As tides rise and fall, tremendous amounts of blue water race through the passages—twice a day from east to west, twice a day from west to east.

Large quantities of small fish are swept along through the narrows. Bigger fish, knowing this, have only to keep their mouths open to be fed—nature's version of a true welfare state.

Human fish can enjoy a wild ride in the same subsea currents with an excellent chance of emerging intact. I was invited to try it by James P. Lewis, an upstate New York industrialist. After a short overnight cruise from Nassau aboard his 78-foot yacht Searcher, we dropped anchor off Rat Cay.

Shooting the Exuma rapids. A number of us donned scuba gear, and one of the yacht's two Boston Whalers dropped us off at a passage's upstream end when the tide was running fastest. Riding the underwater current was pure fun, and we did it over and over. When we reached bottom, 30 to 50 feet down, our speed became more obvious than in the boat.

We zoomed over the sea floor—sometimes grassy, sometimes sandy—without moving a flipper, at about the five-knot clip of a sailboat in a moderate breeze. Groupers headed for cover. Barracudas drifted past, looking for prey. We tried hanging on to a coral head, and maneuvering into the still water in the wake of one, for a shot at a game fish or lobster with an underwater spear gun.

The Boston Whaler above us, drifting with the same current, kept nearby. Because reefs and coral heads slightly retarded the flow at the bottom, the current was faster at the surface, and so the boat tended to run away from us. But the fellows in the boat could see where our bubbles rose. Now and then they would rev up their outboard motor and turn back against the current, to enable us to keep pace with them.

Paying a visit beneath the sea, Dr. von Braun approaches entrance at bottom of cylindrical sea lab, made of rubberized fabric and inflated with air.

A fantastic grotto. We went exploring, too. In one of the cays we found a fabulous cave. Its mouth, below the waterline, could be entered only by diving. Inside, you could surface and breathe normally. You found yourself within a nearly circular dome about 70 feet in diameter and 30 feet high. At the apex was a three-foot opening, as in the Pantheon in Rome. A soft blue light bathed the cathedral-like cave—the combined effect of the lighting from above, and the water-filtered light emerging from four or five connections with the ocean. Red corals and multicolored tropical fish added their hues to a scene of surpassing beauty.

For me, the climax of the thrilling three-day adventure was the sight of a huge leopard ray, easily the size of a grand piano. At first glimpse I was so excited, perhaps alarmed, that I came up fast. I pulled myself together and bravely asked an experienced diver in our group whether I should try to shoot the ray. He advised against it. We both went down and watched the beautiful creature winging through the water for at least a minute.

My companion later explained that I never could have landed that leopard ray.

Continued

There is little chance of killing a ray outright, and it would have taken off for the open sea—leaving me the choice of hanging on to my gun and being dragged along a mile or two, or letting go and losing the gun. Sometimes, he added thoughtfully, there wasn't that much choice. Cases were known where a diver was unable to extricate his trigger finger from the gun while a powerful fish was dragging him away.

Diving from a submarine. My submarine adventure came about when the Underwater Explorers Club of Freeport, Grand Bahama, introduced me to Ed Link—inventor of the Link pilot trainer and, for the past 10 years, a pioneer in underwater-exploring technology. He and John H. Perry Jr., a Florida shipbuilder, designed and built the four-man submarine Deep Diver [PS, July '67] to support commercial and scientific activities at the bottom of the sea.

You board Deep Diver while it rests on the fantail of its mother ship, the 61-foot Sea Diver, which serves as Ed and Marion Link's temporary home and as headquarters for the submarine's operations. An ingenious hoisting device of Link's design, with a strain-gauge-controlled mechanism that always keeps the hoist cable taut, lowers Deep Diver gently into the water even while the tender's stern heaves up and down in heavy seas.

Author in scuba gear meets a spiny puffer fish, during Bahamas adventure of riding rapids and exploring bottom.

I lay prone at the feet of the pilot and looked out through bull's-eyes in the bow as the boat dove 50 feet to the bottom. After a 20-minute cruise, we touched down gently on a sandy stretch between coral heads.

Ed Link motioned to me to join him in the airlock, which permits divers to emerge and reenter the boat under water. He closed a bulkhead door to the forward compartment, and pressurized the lock from compressed-air cylinders, carried outside the hull. When the pressure had risen to the ambient water pressure, he dropped a downward-opening lower hatch. Water stood level at the opening. Three feet below was the sandy bottom.

I lowered my flippered feet to the sand. Hip-deep in water, with my head still in the air-filled lock, I donned my scuba gear and face mask. I put the mouthpiece in my lips, bent down, and found myself floating outside the boat.

Less than 200 feet away were two undersea laboratories. One was hemispherical in shape, with an entrance on the side; the other, cylindrical, and entered from below. Both were of rubberized fabric inflated with air. To keep the buoyant structures from shooting up to the surface, chains attached them to a tray filled with lead bars.

The two labs had just been moved to the site, and were not yet occupied for research, but divers from their tender swam down to join us.

Ed Link and I took advantage of the opportunity to pay the labs a visit. They provided shop space for minor underwater repairs—for instance, to a damaged submarine cable or a sticky valve of an oil pipeline. There were bunks for rest periods, and light enough to read a book. Air in the labs was replenished by adding pure oxygen and removing exhaled carbon dioxide with chemicals—a more economical way than using cylinders of compressed air, since the air's inert nitrogen can be breathed again and again. At a depth greater than about 150 feet, helium would replace nitrogen, to shorten decompression time for surfacing.

After 45 minutes of inspecting these labs, and the enchanting setting of colorful coral reefs, we returned to our "underwater taxi." We swam to the hatch and, one after the other, stood up with feet on the bottom and head in the airlock to remove face mask, lead belt, scuba tank, and flippers. Then we both climbed back into the lock. Ed closed the hatch. Fore and aft, the submarine's electric-powered propellers started humming, and back to the surface we went. I left the boat deeply impressed that Ed Link and pioneers like him have brought the tremendous untapped resources beneath the sea within our reach.

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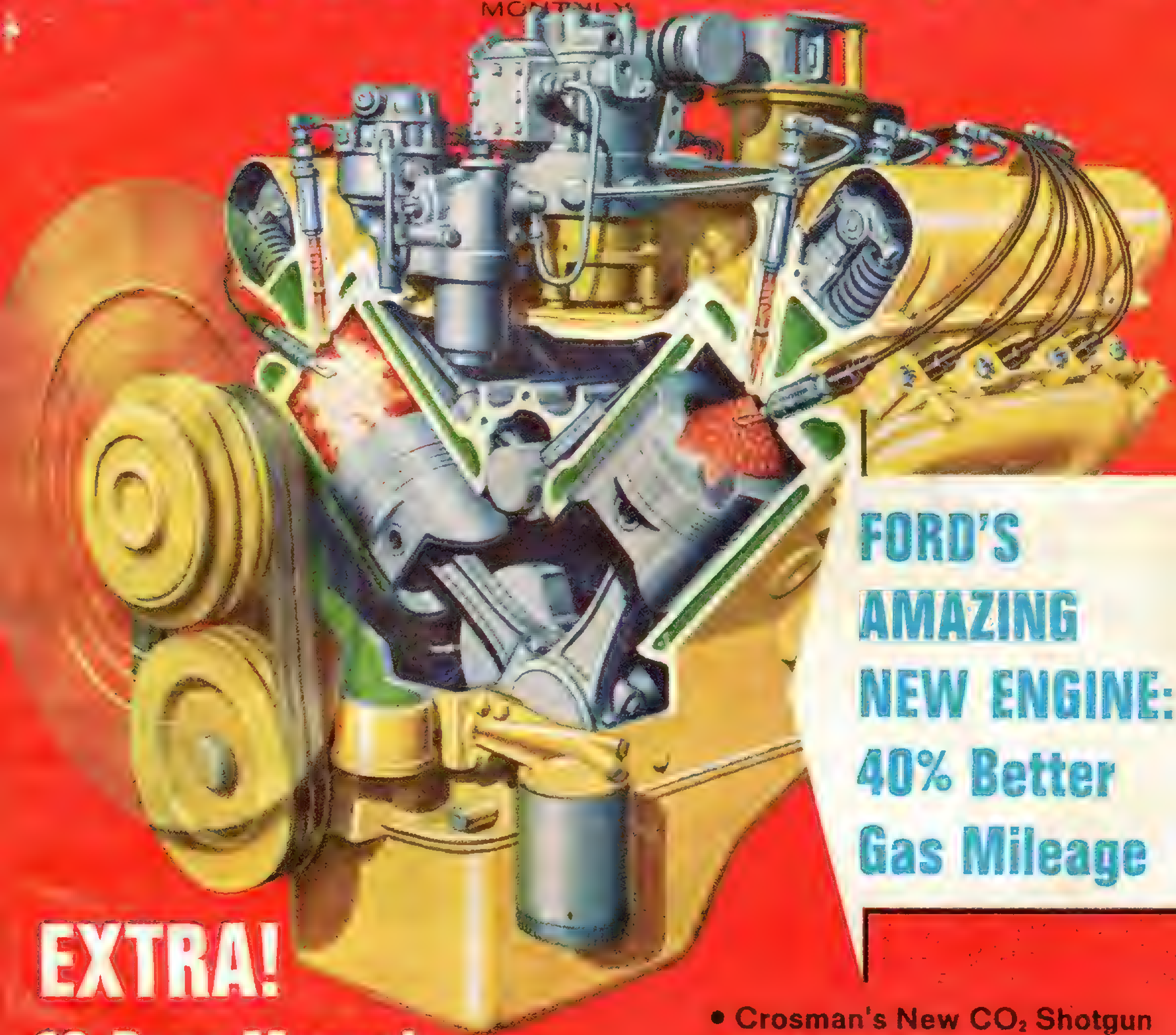

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Coast to Coast by Car in Under 45 Hours—Norbye/Dunne Break Record

The first chemical analysis on another heavenly body is made by Surveyor V's nuclear "chem kit," seen lowered on nylon string to surface of moon in Sea of Tranquility. A ribbonlike cable feeds power to the instrument and brings back its data to be radioed to earth.

In preflight trial at Pasadena with a test-model duplicate of Surveyor VII, excavating tool picks up "chem kit" by knob at its top to place it over a trench dug by tool (bottom of photo). Surveyor VII was the first and only one of the seven to be equipped with both of these devices.

Spacecraft Tell Wha

By Dr. Wernher von Braun

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

When our seventh and final Surveyor perched on the moon near the great crater Tycho and radioed back what it found, early this year, it capped a series of history-making feats by NASA's tripod-shaped spacecraft.

Five Surveyors of the seven launched successfully soft-landed on the moon. Surveyors I, III, V, and VI fulfilled the program's primary aim—testing sites in the moon's flat mares, or "seas," for coming Apollo manned landings.

Little excavating tools on Surveyors III and VII scooped up lunar soil, weighed it, and dug trenches in the moon's surface. "Chem kits" in cube-shaped gold boxes, lowered to the ground by Surveyors V, VI, and VII, told what lunar soil and rocks were made of. Magnificent TV pictures, sent back by all five successful Surveyors, revealed still more about the lunar surface.

Only now are geologists ready to interpret this wealth of fascinating new information. Here is what the Surveyors find the moon's surface is really like:

What the Surveyors tell. Walking on the moon will be a bit like treading on wet sand. You will leave footprints, but you will not sink. Wheeled vehicles will leave tracks but will not get mired. And the rocket exhaust from a landing Lunar

Surveyor VII's excavating tool starts digging a new trench, after scooping out the one to right of it, on highlands of moon near Tycho crater. Operator pushing buttons at Goldstone console, 240,000 miles away, controls motions. After making these trenches, versatile tool placed chemistry set on pile of dug-up soil, to get a subsurface analysis.

Cross on this striking Lunar Orbiter photo of great 56-mile-wide Tycho crater shows nearby landing place of Surveyor VII. It could visit this scientifically intriguing region of moon because earlier Surveyors had completed program's primary task of checking prospective Apollo landing sites in flat mares near lunar equator. (All photos from NASA.)

Wielding chem kits and digging trenches by 240,000-mile remote control from earth, soft-landed Surveyors reveal what lunar surface's rocks and soil are really like

he Moon Is Made of

Module will not blast a deep crater.

Early in our Apollo program there had been grave concern whether a spacecraft landing on the moon might be swallowed up in a deep layer of dust. Some scientists thought the moon's surface, unprotected by an atmosphere from relentless bombardment by micrometeorites over millions of years, might have been turned into a powdery sort of quicksand. Photos televised by our crash-landed Rangers before impact, such as a picture of a loose rock resting on the lunar surface, gave the first strong evidence to the contrary [PS, Nov. '64]. Now the Surveyors have put an end to the "quicksand" bugaboo—both by surviving a landing, and by actually measuring the properties of the lunar soil.

At four widely separated sites, on the level mares selected for our first Apollo landings, the Surveyors find soil of amazing uniformity—giving confidence that our astronauts will not touch down on traitorous and unpredictable terrain.

Facts and figures. Typical soil of a mare consists of very fine particles of about 1/1,000-inch diameter, interspersed with coarser ones and rocks. The fine particles have a definite tendency to stick together, in a kind of cold-welding process that occurs in the absence of an atmosphere. (Some particles even clung to Surveyors' metal parts when thrown hard against them.)

As measured by the Surveyors, the uppermost layer's bearing strength can

Continued

If Apollo astronauts could land on made-to-order ground, says Dr. von Braun, our specifications would come close to what Surveyors have found on surface of moon.

be put this way: Suppose you gently set down on the moon's surface a full beer can—five square inches in area and weighing a pound on earth, but only 1/6 of a pound on the moon. It would sink in only about 1/10 of an inch. (If its moon weight were a pound, it would settle about a quarter of an inch.)

Bearing strength of the lunar surface, like that of snow, increases with depth. The moon's soil would be compacted to a depth of about an inch by a load of three moon pounds (18 earth pounds) placed on a half-dollar (one square inch). The same coin would sink in about two inches deep under a load of eight moon pounds (48 earth pounds).

How did the Surveyors tell us so? One way was with their feet. A strain gauge reported the force, often upward of 1,000 pounds, with which each of a Surveyor's three legs struck the lunar surface. Subsequent TV views showed the depth of the footpad's impression in the ground.

Digging tools tested soil. The little excavating machines on Surveyors III and VII contributed bearing-strength measurements, and others of interest.

Called a surface sampler, each electric-powered tool had a toy-size scoop of six-cubic-inch capacity, with a movable door. Mounted on a lazy-tongs arm within view of a Surveyor's TV camera, the scoop could be raised or lowered, swung through nearly a third of a full circle, and extended to five-foot reach. It could be pressed downward, or dropped from 40-inch height, to gauge the soil's strength by the impression made—and drawn back toward the craft to dig a trench, with the flow of current showing the effort required.

Some 240,000 miles away, the tool's operator sat at a console of the Goldstone tracking station in California, pushing buttons that actuated the device's four electric motors. The scoop responded with enough vigor to dig a trench two inches wide, 30 inches long, and seven inches deep—modest in size but, a proud Surveyor-team member pointed out, "the greatest excavation ever dug by man anywhere, except on earth."

The versatile tool could weigh a scoopful of soil, too, by indicating the amount of current needed to elevate it.

One cubic foot of the porous material forming the uppermost layer of the lunar surface weighs about 50 earth pounds, the Surveyors report. As little as two inches beneath the surface, it weighs about twice that much, or 100 earth pounds. This is about the density of normal dry sand.

What is the moon's surface made of—rock and soil like the earth's, or minerals new and strange to us? First answers have come from a device amounting to a miniature chemistry set, called an alpha scattering instrument, carried on the last three Surveyors.

The five-pound kit occupied a six-inch cubical box with polished gold-plated walls to reflect away lunar heat, and a wide white skirt to support the open bottom. On command, a Surveyor lowered it on a nylon string about 30 inches to the ground. Radioactive curium in the box bombarded the lunar surface with alpha particles, able to penetrate just the top 1/1,000 of an inch of soil.

Some particles bounced back and detectors smaller than a dime measured their energies—which gave a telltale indication of the kind and approximate amounts of various chemical elements in the small sample examined.

Analyzing the moon. History was made by the first on-the-spot chemical analysis of another celestial body, last September, when Surveyor V lowered this instrument to the surface of the moon. Just as in earth rocks, the report came back, the most abundant elements were oxygen (58 percent of all atoms) and silicon (19 percent). Smaller amounts were measured of aluminum, calcium, magnesium, iron, and sodium.

From these preliminary and tentative figures, and the assumption that the oxygen is tied to other elements in oxides, NASA scientists calculated the likely proportions of chemical compounds present. The result identified the lunar material as earth-like basalt—similar to the volcanic

[*Continued on page 182*]

Spacecraft Tell What Moon Is Made of

[*Continued from page 74*]

basalt rock of the Hudson River Palisades and other familiar formations on earth, as well as to "basaltic achrondites" that have been found in meteorites.

In another mare site, Surveyor VI's almost identical analysis confirmed that much of the moon's surface is of this composition. Even in the highlands near Tycho, Surveyor VII's report did not depart widely from the others. (One difference—a little less iron in the highlands' rock—possibly might help account for their lighter color than the mares.)

Surveyor VII, uniquely, carried both a digging tool and a chem kit. Thus the tool could dig up material to be analyzed. It could also pick up and move the analyzer to a desired spot. And the tool dramatically came to the rescue in an unexpected crisis:

After the last Surveyor had brought off the riskiest landing of any, in rough new terrain, the chem kit failed to descend on command. Stuck, it dangled tantalizingly, far from the soil. At the Goldstone console, an operator commanded the excavating tool to try to nudge the box downward and free. It worked, and the day was saved.

A "moon hop." Among the feats of the Surveyors—designed and built by Hughes Aircraft under the direction and supervision of NASA's Cal-tech-operated Jet Propulsion Laboratory, Pasadena—was another unprecedented one. By firing its three vernier engines, Surveyor V hopped from its lunar landing site to a new one eight feet away. Its six-second flight, though short indeed, made it man's first vehicle to travel across the surface of the moon. It also showed that the blast effect of a rocket engine on lunar soil is quite mild.

Most importantly, from a practical viewpoint, our Surveyors show that the moon is actually a most benign place to land upon. If we could have chosen ideal soil conditions for man's first landing on another heavenly body, we would have come pretty close to writing down the specifications actually met by the moon. Even the rugged and supposedly forbidding region visited by Surveyor VII now looks entirely acceptable as a site for later manned landings.


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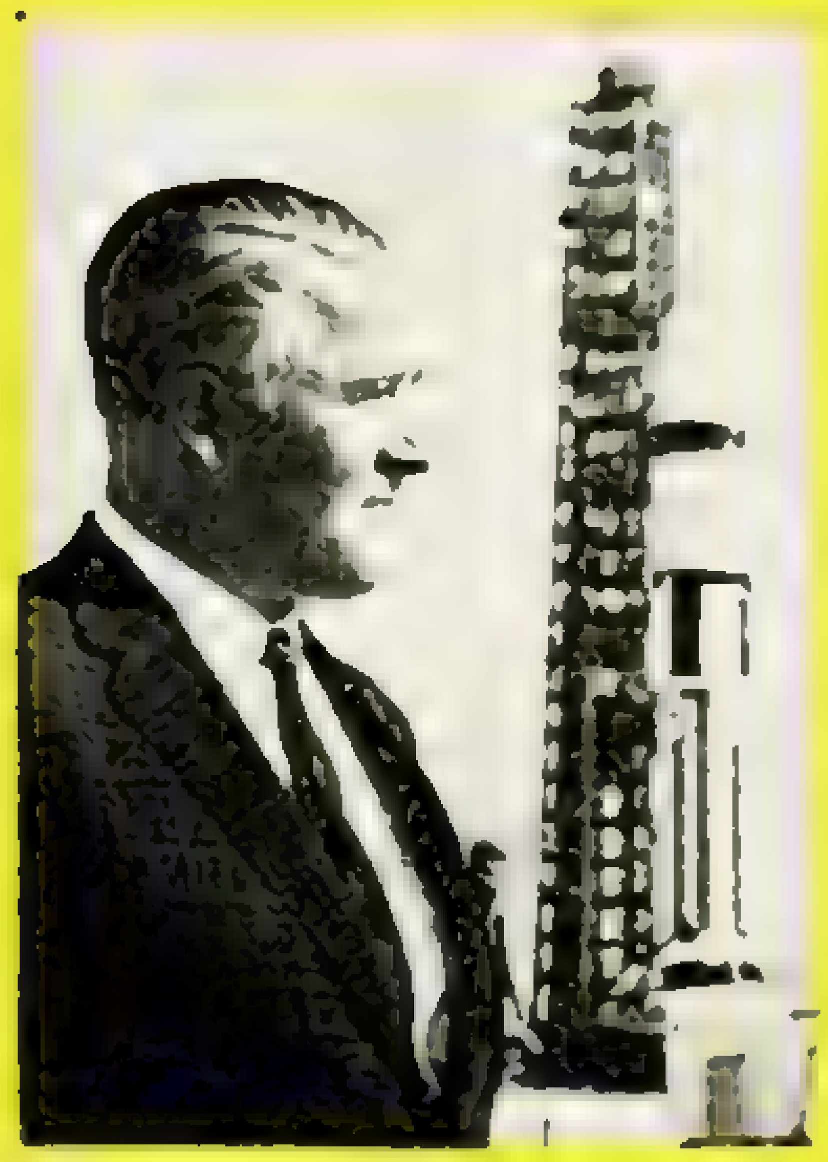
How We'll Get Back

Fast and slow routes from moon to earth

Starting in lunar orbit, returning astronauts can choose from courses taking 86 to 110 hours, to reach spinning earth at right time and place for Pacific splashdown. Fast route (solid line), shorter than slow route (broken line), calls for burning more fuel in power maneuver that begins voyage. This maneuver, over far side of moon, impels craft the opposite way from direction of moon's orbit around earth. Arrival by any route will be near point on earth opposite moon, called "moon antipode."



By
DR. WERNHER VON BRAUN

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

Dr. von Braun watches Saturn 1B rocket readied at Cape Kennedy for unmanned trial of Apollo Lunar Module.

Almost by the hour we can see the beautiful bluish disk of the earth, our destination, grow in size. Wherever the cloud cover permits, we can discern the outlines of continents and islands. In both polar regions we can see the glistening ice fields.

We are homeward bound from the moon. A few hours after our start, when we passed the neutral point where the pull of gravity from moon and earth was equal, we were traveling no faster than a fast airplane. But now that we are back in the earth's firm grip, our speed is picking up relentlessly. It will reach nearly 25,000 m.p.h., or almost seven miles a second, by the time we begin our flaming reentry into the earth's atmosphere.

Three astronauts in an Apollo Command Module will face this experience when they return from a manned lunar mission. In earlier PS articles I have told how our astronauts will land on the moon, and what they will do when they get there. Now we come to the story's highly important conclusion—how they will get back to earth again.

Their return voyage begins from a lunar orbit—where the Command and Service Module (CSM) has remained

Our Apollo astronauts' homeward flight plan offers a choice of slow or fast courses, a cruise in the "barbecue mode"—and a blazing finish at a speed of almost seven miles a second

from the Moon

circling, with a single astronaut aboard as shipkeeper. The two astronauts who landed on the moon have returned in the Lunar Module ascent stage, completed their docking maneuver, and crawled back into the Command Module (CM) to join him. The ascent stage, its duty done, then is jettisoned.

Since the moon's gravity holds the CSM captive in lunar orbit, a power maneuver that adds tangential speed is needed to free it. Further, this maneuver must be so timed as to launch the CSM the opposite way from the direction in which the moon orbits the earth. Then the slower earth-orbiting speed of the CSM will enable the earth's gravity to take effect on it and pull it homeward.

Suppose we take the three astronauts' places in the craft and see what it is like to carry out this flight plan.

We align our guidance system, finish checking remaining equipment, and report back to earth that we are ready to go.

Flight Control in Houston thereupon selects a return trajectory for us. Its transit time will roll the recovery carrier, on the revolving earth, into our landing area by the time we get there.

Choosing the course. The more fuel we burn in the power maneuver, the shorter and faster our trajectory will be. Thus a choice of courses taking from 86 to 110 hours—a full 24-hour difference—is available. This gives us the option to perform our power maneuver during any two-hour far-side pass in our orbit around the moon. The location of the Pacific recovery forces can then be taken into account simply by selecting a longer or shorter transit time.

At the appointed moment, we fire up the Service Module propulsion system. A mild *g*-force presses us down in our couches. The maneuver adds about 2,700 feet per second to our orbital speed around the moon, enough to get away.

A few hours later, from our astronomical fixes, our flight path looks okay for the present at least. This is confirmed by the radio trajectory check received and analyzed by Flight Control.

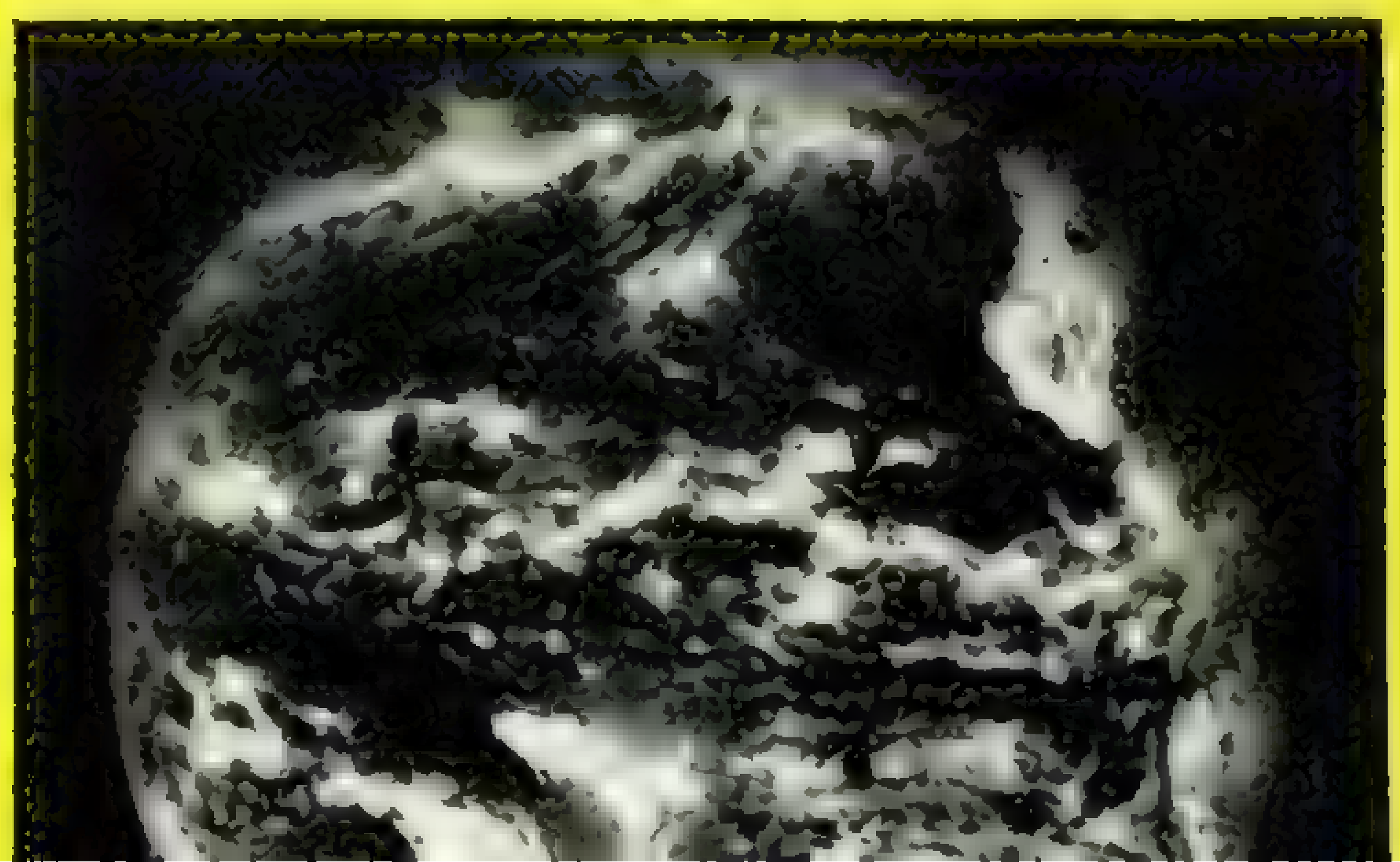
After 24 hours more, Flight Control advises us that they want a minor midcourse maneuver, after all. They give us the numbers to be fed into our computer. We turn the craft into the programed attitude and, as the hand of the countdown clock hits zero, the Service Module engine fires for a few seconds. Then we resume coasting through space.

We are flying in the "barbecue mode" —which means that the CSM is slowly rotating on its axis, with its broadside toward the sun. This distributes the sun's heat evenly over the vehicle and avoids undue heating or cooling—of propellants, in particular.

Where ocean recovery forces await us hangs upon an interesting characteristic of all available return paths. Imagine a long needle stuck through the centers of earth and moon. The earthward power maneuver will always take place near the point where the needle sticks out on the moon's far side. And reentry and landing will always be near the point where the

Continued

Cloud-flecked disk of earth, pictured from 22,300 miles away, will be a beautiful sight to homecoming spacemen. NASA's ATS-1 satellite took this photo.

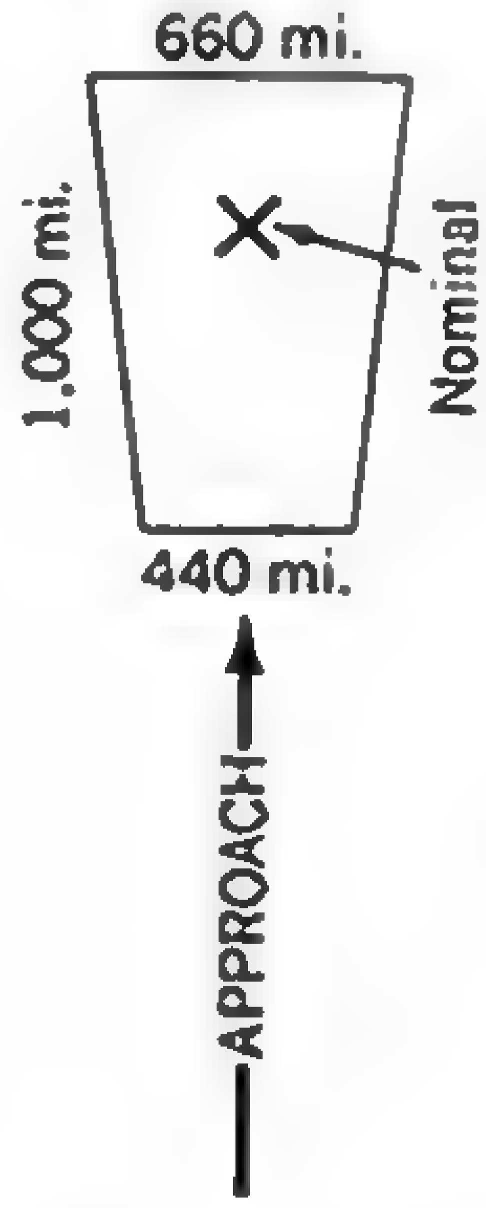


needle's opposite end emerges from the earth, called the "moon antipode."

Now, since the moon's orbit is inclined to the earth's equator by 22 to 25 degrees, the moon splits its time about half and half above the earth's northern and southern hemispheres—and so the moon antipode crosses the equator twice a month. This means that we shall need two sets of recovery forces in the Pacific, to be prepared for all possible launch dates, and to respond at short notice to any slippage. One will be stationed north of the equator, at Hawaii; the other, south of the equator, at American Samoa.

Well into our third day of flight, we are nearing our target. A few hours before things begin to happen again, we detach our Service Module.

The reentry. Now comes the most demanding and crucial phase of the entire mission. The fiery reentry will take place at far greater speed than any astronaut descending from earth orbit has ever experienced. And it will call for a striking maneuver, new to manned space flight, if the precision approach has gone as planned.



Our reentry officially begins at 400,000 feet, just over 75 miles, above the earth. A "nominal" or ideal flight path will incline 6.2 degrees downward with respect to the local horizon, as it passes this reference point.

In this nominal case, after air drag has reduced our speed sufficiently to assure safe capture, our guidance system will steer the CM through a "ballistic lob." This means that the capsule will rebound upward from the atmosphere and come down again for a second and final reentry farther on. The splashdown will be 2,000 miles beyond where the first reentry began, if we do not make use of the capsule's limited capability for aerodynamic maneuvering.

While the cone-shaped CM has no wings, it can nevertheless be considered an airplane of sorts. Its center of gravity is quite a way off the center line. Hence its normal attitude, as it sweeps through the atmosphere, produces a lift force tending to raise the flight path. By banking the CM, we can use the same lift force to steer it to left or right. Or we can roll the CM upside down—and use the inverted lift to force the capsule into deeper and denser atmosphere, to forestall an uncontrollable skip-out from an overshoot approach.

Our sophisticated guidance system will make full use of this limited maneuvering capability. If necessary, it will cope with an off-nominal entry. It may cancel the ballistic lob if entry is at too shallow an angle to reduce initial speed fast enough.

It can also introduce desirable course changes—to bring us as close as possible to our recovery ship, and for other reasons. Suppose weather at the intended landing spot has changed for the worse since our commitment to the flight path three days before. The guidance system can then be instructed to lengthen, shorten, or divert our path to a splashdown.

This makes the "footprint" area where a landing is possible (diagram at center of page) about 1,000 miles long—with a width of 440 miles at the "heel" and 660 miles at the "toe" of the footprint.

The landing. Some six minutes before splashdown, barometric switches and timers, backed up by manual controls, activate a rapid sequence of events:

The heat-shielding cover of the CM's parachute compartment is jettisoned. Drogue chutes, pilot chutes, and finally the three main chutes emerge in turn. From the last, our CM dangles securely at an angle of 27½ degrees, with the astronauts' toes in the "down" direction.

To reduce impact hazards, we dump remaining attitude-control propellants and blow off high-pressure helium. We turn on the radio beacon for the search-and-rescue people, close our cabin pressure-relief valve—and brace ourselves for the splash.

Hoisted safely aboard the recovery carrier, the astronauts will still face temporary quarantine, against the remote possibility of having brought back dangerous lunar organisms. But plucking them from the sea will have concluded the story of their dramatic return flight from the moon.

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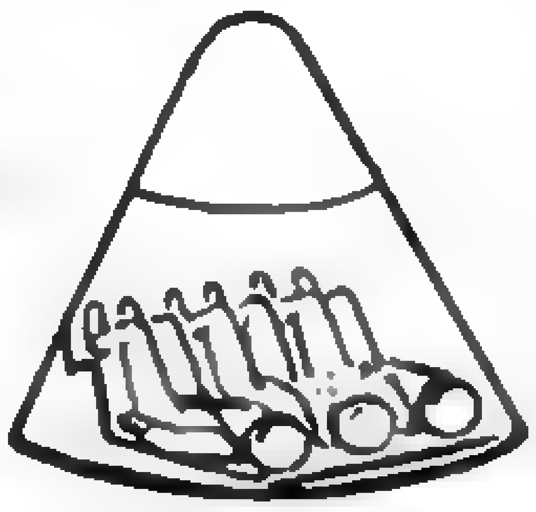

MISSION C. First manned Apollo mission. Earth-orbiting flight (low orbit).
MISSION D. First manned Saturn V mission. Earth-orbiting flight (low orbit).
MISSION E. Rehearsal of moon mission. Earth-orbiting flight (high orbit).
MISSION F. Flight around moon and descent to within 10 miles of lunar surface.
MISSION G. THE LUNAR LANDING.

Vehicles. Mission C: Uprated Saturn I; CSM. All other missions: Saturn V; CSM and LM.

Crew. Three, on each mission. They will be designated "Commander," "Command Module Pilot," and "Lunar Module Pilot." Mission G's Commander and LM Pilot will land on the moon, with the LM, while the CM pilot remains in the moon-orbiting CSM.

Hand-held 4½-pound TV camera, developed by RCA and due to go aloft on first Apollo manned flight, will transmit first live pictures of orbiting American astronauts and views seen from their craft.

Here are the steps by which our manned Apollo missions will lead to landing men on the moon

By DR. WERNHER VON BRAUN

Director of NASA's George C. Marshal
Space Flight Center, Huntsville, Ala

When three astronauts in a cone-shaped Command Module are rocketed into orbit a few weeks hence, our Apollo lunar-landing program will be on the final straightaway stretch.

It has come around the corner with successful unmanned flight tests of its Saturn V rocket and all spacecraft modules. What we call Mission A was the demonstration by our first two unmanned Saturn V flights of the soundness of the launch vehicles and the adequacy of the Apollo heat shield. Mission B was the launch last January of an unmanned Lunar Module (LM) by an Uprated Saturn I.

Yet, even now, it would be reckless and unrealistic simply to assemble the whole stack, put a crew aboard, and blast off without further ado for a lunar landing. First, manned partial-mission flights must try out the spacecraft, their subsystems, and procedures for flying them, in the space environment for which they were designed.

First manned Apollo. Next step on the remaining "stairway to the moon" will be Mission C—the initial manned flight of the Apollo Command and Service Module (CSM), and our first manned space flight since the last Gemini nearly two years ago. It will be carried out by astronauts Schirra, Eisele, and Cunningham in the soon-to-be-launched Apollo 7.

Mission C will include quite a number

MOON

of "firsts." This will be the debut in manned flight of the new Apollo Command Module, redesigned and drastically fireproofed. The flight will introduce the newly adopted safeguard of substituting a nitrogen-oxygen mixture, as a prelaunch cabin atmosphere, for the 16-pound-pressure pure oxygen of the past. A hand-held RCA TV camera is expected to be carried aboard, providing a novelty for the public—live TV views of our astronauts in space.

Boosted by a two-stage Uprated Saturn I, Mission C will be a low earth-orbiting flight lasting nearly 11 days. It will not carry a moon-landing Lunar Module, but will serve simply to try out all systems of the CSM—the Command Module, and the attached Service Module that provides propulsion and other needs.

During Mission C the CSM's orbit will be varied from a nearly circular one,

Continued

Apollo 7's Command Module, below, is readied at Cape Kennedy to go atop Uprated Saturn I rocket at right—and carry three astronauts into earth orbit on Mission C, first of coming Apollo manned flights.

averaging 155 statute miles high, to an elliptical one ranging up to 270-mile height. To simulate a rendezvous with a Lunar Module, the crew will try to rendezvous from 170-mile distance with the launch rocket's orbiting second stage.

First manned Saturn V. Apollo 8 and its 10-day Mission D, coming next, will undoubtedly be the most complex manned space flight ever attempted. It will be the first manned trial of the three-stage Saturn V—which, with both CSM and LM in place, will tower 363 feet high. Although Mission D will get no farther from earth than about 160 miles, it will exercise the entire stack of equipment required for a flight to the lunar surface. Here are highlights of its plans:

Coming manned missions, says Dr. von Braun, will build up experience needed for final assault on moon.

First day: The launch puts the third stage and spacecraft in a 119-mile circular orbit. The CSM separates, turns squarely around, and extracts the LM from Saturn V's third stage. The combined spacecraft climbs to a higher elliptical orbit under Service Module power. Meanwhile a second and third burn of the unmanned Saturn V third stage propel it out of the earth's gravitational field, as if bound for the moon.

Second day: The spacecraft cluster simulates the deboost into lunar orbit by firing the Service Module propulsion system. The last of three burns leaves the craft in circular 154-mile orbit.

Third day: The LM crew of two crawl through a tunnel from the Command Module (CM) to the LM for a complete LM checkout, including short burns of its descent stage under automatic and manual control.

Fourth day: Now comes a "space walk." The LM Pilot, with a self-contained life-support pack, proves it feasible to go from the LM back to the CM *outside* the vehicles. (In a lunar flight the LM crew, returning from the moon to the CSM, would fall back on this plan if damage from a hard docking prevented use of the crawl tunnel.)

Fifth day: The crew reenter the LM and it separates from the CSM. The LM crew set up (but do not execute) rendezvous maneuvers with the CSM, using the descent stage's propulsion system. Then the descent stage is jettisoned. The LM's ascent stage, using only its reaction control system for propulsion, effects a rendezvous with the CSM, and the LM crew return to the Command Module.

Sixth to 10th day: The crew perform navigation exercises and various experiments—and retry their earlier tasks, to practice and improve the technique of these procedures.

Rehearsal for moon flight. Nine-day Mission E in Apollo 9, taking its crew 4,600 miles from earth, will rehearse a lunar flight's principal maneuvers.

As if to start the spacecraft on a lunar trajectory, Saturn V's third stage will have a second burn—but of half the duration for a flight to the moon, so that it actually puts the spacecraft into an elongated elliptical earth orbit with a high point of about 4,600 miles. The CSM will turn around, dock to the LM, and extract it, as in a lunar flight. A short burn of the Service Module engine will simulate a midcourse correction; and a long burn, braking for insertion in lunar orbit. This and a lunar-orbit "fine-trimming" maneuver will actually bring the spacecraft down to a circular 173-mile earth orbit.

Entering the LM, the Commander and LM Pilot will fire its descent engine to simulate an emergency CSM/LM return to the earth under LM power. Freeing the LM, they will enact a descent toward the moon, an "abort," and a return to the CSM, which they will reenter. Detaching the LM ascent stage, they will simulate a CSM rescue rendezvous with an incapacitated ascent stage. Lastly, a Service Module burn will represent a normal earthward maneuver from lunar orbit. From a resulting elliptical earth orbit of 104 to 230 miles, the CSM will de-orbit and splash on the ninth day.

Flight around the moon. Newly announced by NASA as a tentative next

[*Continued on page 213*]

Stairway to the Moon

[*Continued from page 92*]

step, Mission F is a circumlunar flight. The spacecraft cluster will circle the moon for days in lunar orbit; and the manned Lunar Module will separate from the CSM and descend almost to a lunar landing; before returning to a rendezvous.

Mission F thus would be a complete lunar-landing flight, minus the touchdown. Possibly it may be skipped, if results of eariler missions warrant going directly to a lunar landing; but by present expectations it will probably be flown, with Apollo 10.

In its plan, the manned LM will separate from the CSM 25 hours after arrival in lunar orbit, about 70 miles above the moon. A short burn of the descent-stage engine will put the LM in an elliptical orbit ranging from that altitude down to only 9.2 miles above the lunar surface—three times as near as our picture-taking Lunar Orbiters' closest approach.

If the LM crew were going to land, an eight-minute retardation burn would begin at this low point. In Mission F, instead, other burns will raise the LM's flight path and bring its ascent stage back to a rendezvous with the CSM—the descent stage being jettisoned midway.

A mock rescue. Three days later, with all three men safely back in the Command Module and the LM ascent stage cast adrift, the CSM will simulate a "rescue" mission to the unmanned and passive ascent stage. This will show the CSM able to come to the help of a disabled ascent stage in lunar orbit—using its own VHF ranging-tracking system, with no navigational assistance from the earth.

Mission F would thus provide practical experience in operating navigation and communication systems over lunar distances; determining and correcting a lunar orbit; indentifying landing sites, beginning a manned lunar landing; making a manned rendezvous in lunar orbit; and demonstrating rescue capability.

Those are the steps of the stairway to the moon that will lead up to Mission G—the actual lunar landing. Thus the crew for the final assault will not have to master all its complexities from scratch, in one daring try—but can draw upon the combined experiences of the crews of the earlier partial missions. PS

*NOTE: Article not available

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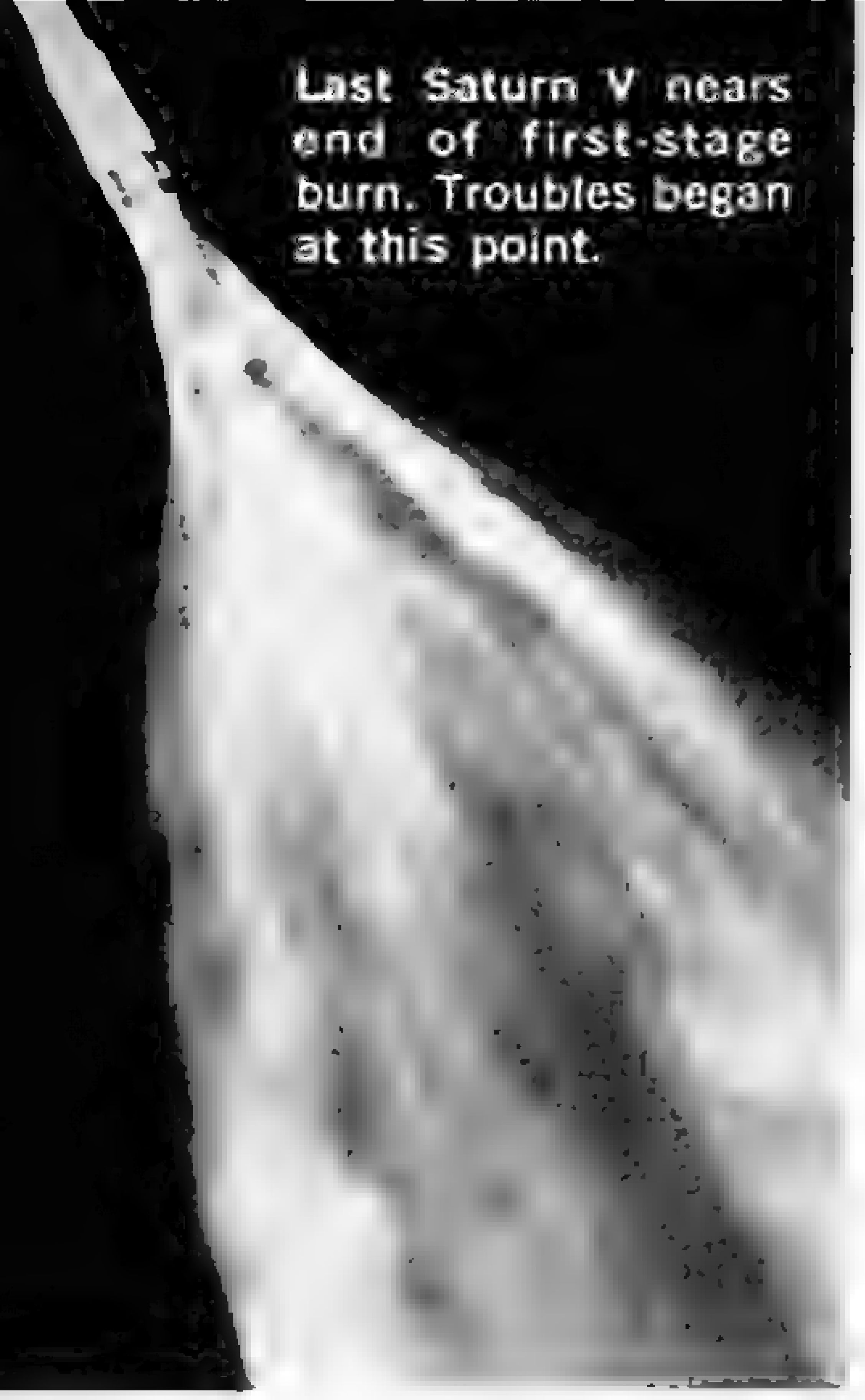


Last Saturn V nears end of first-stage burn. Troubles began at this point.

The Detective Story Behind OUR FIRST MANNED SATURN V SHOOT

By solving the mystery of what went awry last time, engineers give the giant moon rocket a "go" to carry astronauts on the next Apollo mission

By DR. WERNHER VON BRAUN

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

SKETCHES BY THE AUTHOR

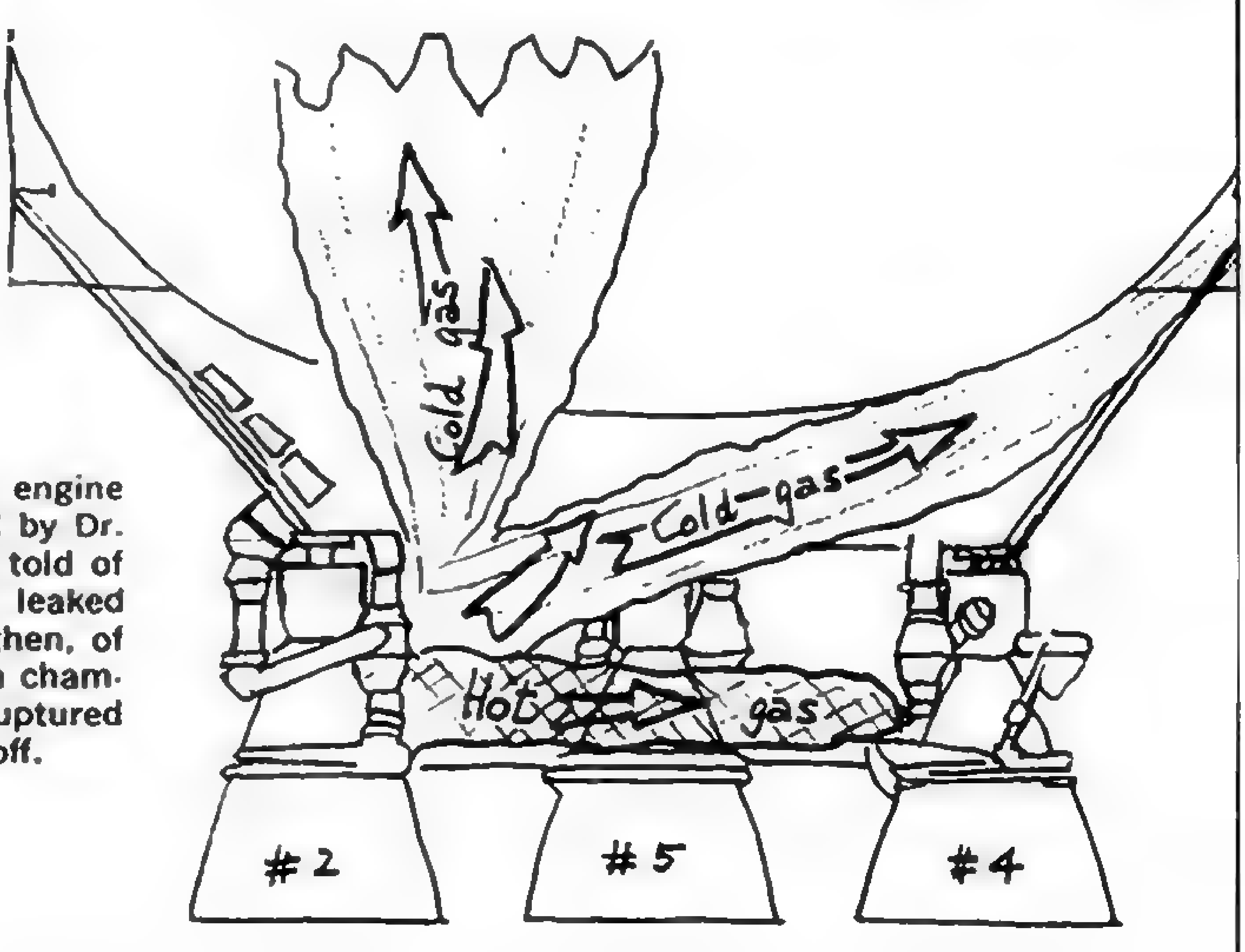
A few weeks hence, at Cape Kennedy, the first manned Saturn V will thunder aloft—our 363-foot-high moon rocket. A triumph of detective work has cleared the way for astronauts to ride it.

So far, just two of the giant rockets have been launched, both unmanned. The first Saturn V flight went off flawlessly late last year. A string of mishaps, in contrast, beset the second one last April. But the diagnosis of these has been so conclusive, and the remedies so successful, that the unmanned trial will not need to be repeated. NASA has decided to go right ahead and fly the third Saturn V manned.

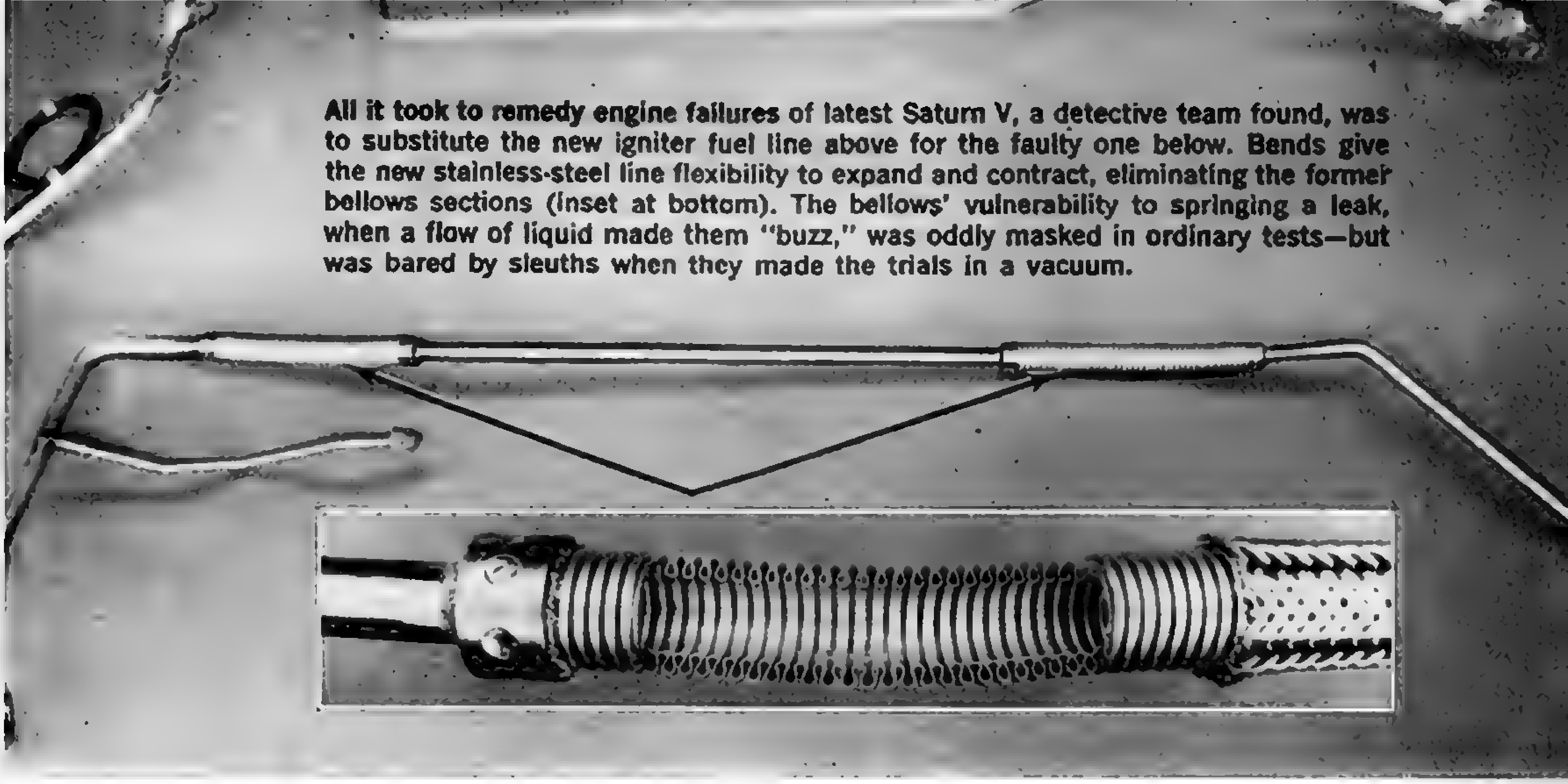
The story of how the second Saturn V flight's troubles were identified resembles a detective thriller. It illustrates, too, modern methods of shaking down a complex space vehicle.

The last flight. The second Saturn V's takeoff at the Cape was faultless. For two minutes everything looked like a repeat of the first Saturn V's textbook performance. Then came a little excitement in the launch control center when, around the 125th second, telemetered signals from accelerometers indicated an apparently mild "Pogo" vibration.

This is a lengthwise oscillation, named after the motion of a Pogo stick, which had caused no little concern with the earlier Titan-boosted Geminis. It makes a space vehicle lengthen and shorten like a concertina, several times a second. But



Clues to conking-out of second-stage engine No. 2, on last Saturn V, are sketched by Dr. von Braun. Thermocouples on rocket told of flow of cold gas, as liquid hydrogen leaked from igniter fuel line and vaporized; then, of hot blast, as fire gas from combustion chamber spurted like blowtorch from ruptured line. Losing thrust, engine shut itself off.



All it took to remedy engine failures of latest Saturn V, a detective team found, was to substitute the new igniter fuel line above for the faulty one below. Bends give the new stainless-steel line flexibility to expand and contract, eliminating the former bellows sections (inset at bottom). The bellows' vulnerability to springing a leak, when a flow of liquid made them "buzz," was oddly masked in ordinary tests—but was bared by sleuths when they made the trials in a vacuum.

the Pogo vibration disappeared at about the 132nd second.

The second stage's five J-2 engines, burning liquid hydrogen, ignited exactly on schedule. But engine No. 2 soon gave signs of trouble. After burning for almost 4½ minutes, it suddenly lost thrust, and its low-thrust detection switch turned it off completely. Engine No. 3—which had performed perfectly up to this point—shut itself down a second later.

Deprived of two-fifths of its million-pound thrust, the second stage bravely fought on upward—with the trouble-sensing guidance system altering the climb path to help—and labored overtime before dropping off. The third stage's single J-2 engine started, and the bird arrived in a somewhat off-normal but stable parking orbit. When it had circled the earth twice, a radio command to reignite the third stage was sent. But the J-2 engine failed to respond.

To get the most out of the rest of the flight, the Command and Service Module carried in the nose was commanded to separate from the disabled third stage. After two burns of the Service Module, the Command Module made its reentry and was successfully recovered.

Had the flight been manned, the astronauts would have returned safely. But the flight clearly left a lot to be desired. With three engines out, we just cannot go to the moon.

Despite the J-2's impressive reliability in tests, two of the engines had conked out in second-stage flight, and a third had balked in orbit. Why, suddenly, three failures on a single flight?

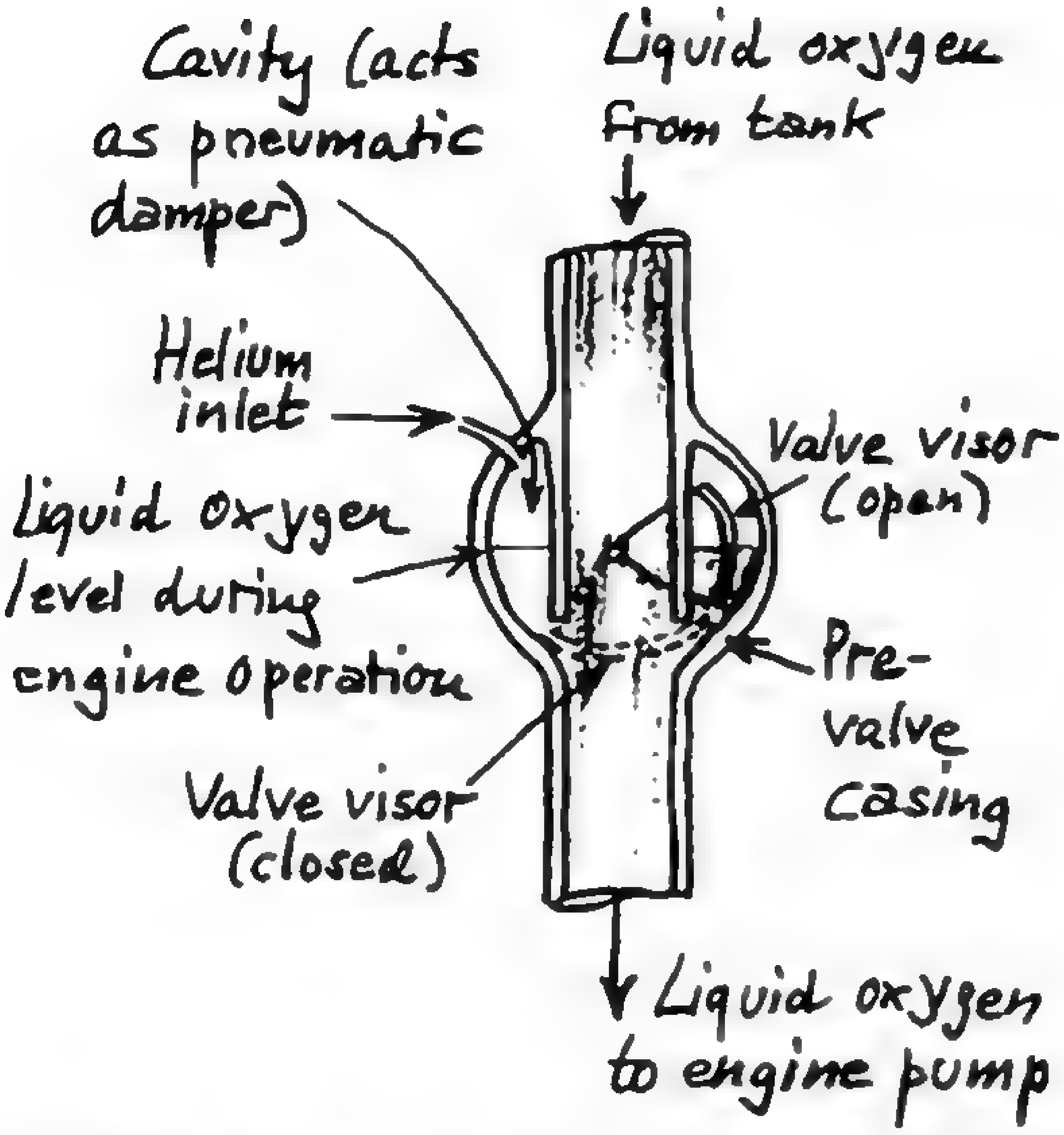
Sleuths find clues. A joint detective team of engineers from NASA's Marshall Space Flight Center and from Rocketdyne, the J-2's maker, went to work. Soon they discovered clues. Counting time from second-stage ignition, telemetered temperature readings of thermocouples in the second stage's tail told this story:

- At about the 70th second, a flow of cold gas was detected, which could come only from a liquid-hydrogen fuel leak. The flow pattern clearly located the leak in the upper part of engine No. 2.
- The cold flow seemed to be increasing from the 110th second on, the time when engine No. 2 began to falter.
- Between the 262nd and 263rd seconds, a sudden blast of very hot gas came from the same place—just a split second before engine No. 2 shut itself off.

This short hot blast before shutdown was the giveaway. Only the fuel line to the J-2's igniter could fail in just this way. (The igniter is a hydrogen-oxygen pilot flame that helps start the engine, and burns while it operates.)

A leaking igniter fuel line would spray the surrounding area with cold hydro-

Continued



Successful cure for Saturn V's Pogo vibration, from slight pulsation in thrust of its mighty first stage, puts a shock-absorbing pneumatic damper of helium gas in each engine's oxygen prevalve.

gen, while it kept feeding some fuel into the igniter. But the moment the line failed completely, high-pressure fire gas from the rocket engine's combustion chamber would back up in it and rush out of the breach like a blowtorch, rapidly widening the uncooled opening. And when the engine's combustion pressure dropped below a certain point, the low-thrust sensing device would turn off the engine, by closing fuel and oxygen "prevalves" that control the propellants' flow to the engine pumps. That explained why engine No. 2 shut down.

But what made the healthy No. 3 engine quit an instant later? Embarrassingly, a plain human goof. Because of a mistake in wiring, the electrical signal intended to close engine No. 2's lox (liquid-oxygen) prevalve went instead to engine No. 3's prevalve. Thus engine No. 2, while it shut itself off by closing its own *fuel* supply, cut off engine No. 3's *lox* supply, too.

The third stage's J-2 engine shared the troubles of second-stage engine No. 2. During its first burn of 170 seconds there were the same telltale signs of leaking and rupture of the igniter fuel line, including the final hot blast. That put the engine out of commission—and so it could not be restarted.

What ailed the igniter fuel lines? Tortured in tests before, they went on the rack again. They proved immune to increased pressures and flow rates, and to a far more severe shaking up than in flight. Next came a study of resonant conditions: Did bellows sections in the lines, which provided flexibility for expansion, "buzz" at certain flow rates?

It turned out that they did—but it seemed impossible to make them fail as a result. Then eight lines were placed in a vacuum chamber. Liquid hydrogen flowed through them at the proper rate and pressure. Within 100 seconds, every line failed at the bellows section!

Movies made of bellows' tests solved the mystery. When the test chamber was *not* evacuated, surrounding air was liquefied by the extremely low temperature of the bellows (—350 to —400 F.) when liquid hydrogen flowed through it. The liquefied air, trapped by metal braid around the bellows, effectively damped its vibration at resonant points. Evacuate the chamber, and (as in space) the protective damping effect was gone.

Once this diagnosis of the engines' failures was made, the remedy was simple. New igniter fuel lines, with bends in the stainless-steel tubing for flexibility, eliminated the bellows sections—and that was all there was to it.

Then, the Pogo fix. The Marshall center set up a Pogo Task Force, too—supported by experts from other NASA centers, universities, and industry. The team studied the first-stage F-1 engines, made shake tests of parts of the Saturn V/Apollo structure, and reported:

Such is the nature of a rocket engine's operation that the F-1s' thrust and combustion chambers slightly pulsate, at a natural frequency of about 5½ cycles a second. The entire Saturn V with a spacecraft in its nose has a natural frequency, too, at which it is especially susceptible to longitudinal (concertina-like) vibration. Increasing as propellants are consumed, this frequency also approaches 5½ cycles a second at about 125 seconds after takeoff.

When the structure's responding frequency matches the engines' driving frequency, Pogo vibration can occur.

While not necessarily destructive, it un-

[*Continued on page 209*]

Our First Manned Saturn V Shoot

[*Continued from page 100*]

desirably imposes an extra, fluctuating fraction-of-a-*g* load on the vehicle and crew. (Sitting atop the long Saturn V stack, the relatively light spacecraft is subjected to even higher Pogo-vibration loads than the engines at the other end that cause the problem.)

The Pogo team's solution: Detune the two frequencies by placing a pneumatic shock absorber in the liquid-oxygen line of each of the five F-1 engines.

Cavities in the engines' lox prevalves make this easy. Just fill them with helium gas—which doesn't condense at liquid-oxygen temperatures—and you have the desired shock absorbers. The first stage's ample supply of helium for pressurizing the fuel tank can be tapped to do it. Thus the Pogo fix was made.

Both a first stage with this shock-absorber modification, and a second stage with the new igniter fuel lines, were successfully test-fired last August at the Marshall center's Mississippi Test Facility. The two simple fixes qualify the Saturn V for manned flight.

New plans. Called Apollo 8, the first manned Saturn V flight will follow the initial manned Apollo mission, boosted by an Uprated Saturn I—Apollo 7, due to have taken place when this is read.

Apollo 8, likewise, will carry the Command and Service Module (CSM); contrary to earlier plan, it will not include the Lunar Module, whose debugging is taking longer than expected. Plans for the first manned Saturn V, and later missions, had therefore to be revised.

Apollo 8's new basic mission plan provides operations with the manned CSM in low earth orbit—and, after separation of the CSM, an unmanned orbital launch of the Saturn V's third stage into an escape trajectory possibly grazing the moon. However, if Apollo 7 has gone very well, possible options are under consideration for the Saturn V. It might launch the CSM several thousand miles into space. There is even a remote possibility of a spectacular swing around the moon by the manned spacecraft. That a mission as bold as the last is even considered, for the first Saturn V to be manned, bespeaks planners' confidence that all about it has been set aright. PS

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Smokey Yunick vs. a Car-Clinic Computer

SEE PAGE 74

Can Atomic Scientists Ban the Bomb?

By FLETCHER KNEBEL

Author of "Vanished"

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16-Page Extra!

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What Every Owner and Buyer Should Know

A famous space leader tries zero-gravity flying himself—and here is his own story of the eerie experience

What It's Like to Be Weightless

By DR. WERNHER VON BRAUN
Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

"Like a saint ascending to heaven," author rises horizontally (left) and floats (center) in zero-g. In space suit (right), he confers with companion, Dr Stuhlinger—who also is levitating in other views

You just can't imagine what a half-minute of weightlessness is like until you've tried it. I recently had that weird experience in an airplane making zero-gravity maneuvers by flying along a ballistic trajectory.

Here is a means of creating true weightlessness, even if only for a limited time. It serves to study tools, procedures, and the time required for astronauts to perform tasks while weightless—key factors in planning our future manned spaceflight ventures.

All our work at NASA's Marshall Space Flight Center on our new Orbital Workshop and Apollo Telescope Mount—a prototype manned space station, and an attached observatory—depends critically on a sound understanding of astronauts' difficulties and constraints under zero gravity. I would have felt remiss, therefore, if I had not tried it myself.

The Air Force Systems Command has assigned two modified KC-135 airplanes at Wright-Patterson Air Force Base, Ohio to the joint NASA/AF zero-g project (The KC-135 was developed as a jet tanker for the Strategic Air Command; the famous Boeing 707 is its commercial version.)

The "Weightless Wonder." After a fitting test with a space suit, I boarded one of these planes, nicknamed the Weightless Wonder, and soon we were climbing to altitude. Sharing the experience with me was my old associate, Dr. Ernst Stuhlinger, Director of the Space Sciences Laboratory at the Marshall Space Flight Center.

In the forward part of the cavernous main cabin we found a mockup of some familiar hardware: an Apollo Command Module and a Lunar Module section complete with crew couches, crawl tunnel, and the probe-drogue assembly used in the two modules' docking maneuver.

Studies had just been made in flight of the zero-g procedure for stowing the

Making like Superman, Dr. von Braun enjoys exhilarating feeling of being weightless. With successive trials, he learned knack of soaring the whole length of plane's cabin, after a push-off from one corner.

docking probe beneath a crew couch after a successful docking, to provide a free passage through the crawl tunnel. Similar mockups for elements of the Orbital Workshop and the Apollo Telescope Mount are being readied at the Marshall center for installation in the KC-135; we were glad to see where they would go.

The aft portion of the cabin, set aside for free-floating and low-g walking, would be our main playground today. This space is padded all around, and a thick soft mattress covers the floor.

Here we were in the competent hands of Don Griggs, Aeronautical Systems Division's Zero-G Test Director. Don once volunteered to pinch-hit for a colleague who helped the astronauts in their early zero-g training. He became so enamored of the job that by now he's logged 8½ days of zero-g, all in 30-second bits!

The zero-gravity corridor. A typical flight begins at about 30,000-foot altitude. At one end of a "zero-gravity corridor" set aside by the FAA along the Ohio River, the pilot commences a shallow dive at maximum engine power.

Upon reaching Mach .88 (about 520 m.p.h.), he makes a 2½-g pullout until the plane reaches a climb angle of some 45 degrees. By now the altitude is back to about 30,000 feet.

Abruptly the pilot retards all four throttles to "idle." Using the elevators, he brings the reading of a special "g-gauge" to zero. Once this gauge's reading drops below .2 g, a second indicator—a "vernier g-gauge" whose entire scale is limited to the range between plus and minus .2 g—enables him to maintain precisely a zero-lift ballistic trajectory (pictured on the next page). The idling engines just cancel aerodynamic drag, so there is no longitudinal acceleration, either.

The plane reaches the apex of the ballistic arc, some 35,000 feet high, about 15

Continued

"Moon-walking" at 1/6 g was tried by author, in "shirtsleeves" and in a pressurized space suit.

seconds after reducing power. Another 15 seconds, and it is diving at 45 degrees through the 30,000-foot level. A second 2½-g pullout is made. It can be followed immediately by another 30-second zero-gravity arc—or the plane can simply level off for normal flight.

The zero-gravity corridor is long enough to permit three successive arcs. After a 180-degree turn, three more arcs may be flown on the opposite heading.

We try it. Our first zero-g runs were in "shirtsleeves"—actually, Air Force fatigues. Don Griggs, who was in constant interphone contact with the cockpit, told us to lie down on our backs and stare at the cabin ceiling.

The engines roared to full power. Quite gradually the g-level rose until the full 2½ g's pressed me down on the mattress. Brilliant light flooded the cabin to photograph zero-g training.

Suddenly the engines' roar stopped. A tug from Don Griggs signaled that "we were there." We were indeed.

Like a saint ascending to heaven, I rose from the mattress in a horizontal position—and found myself floating halfway between floor and ceiling.

Don turned me around and I tried to "swim." No soap. Drifting to a wall, I made an inexpert attempt to push myself back to the cabin's center—a major blunder. Before I knew what was happening, I was spinning head over heels.

The warning horn sounded—10 seconds to go. Someone pulled me down to the mattress. Then the beginning of the 2½-g pullout nailed me to my landing spot.

But with each zero-g arc, as we tried it repeatedly, we became more at home in that eerie weightless state. From one corner, we would push ourselves off as if to swan-dive from a springboard, and soar the whole length of the cabin.

How does weightlessness feel? "Exhilarating" is the word that comes to mind. Flying through a room seems so easy, you wonder that man has lacked that gift.

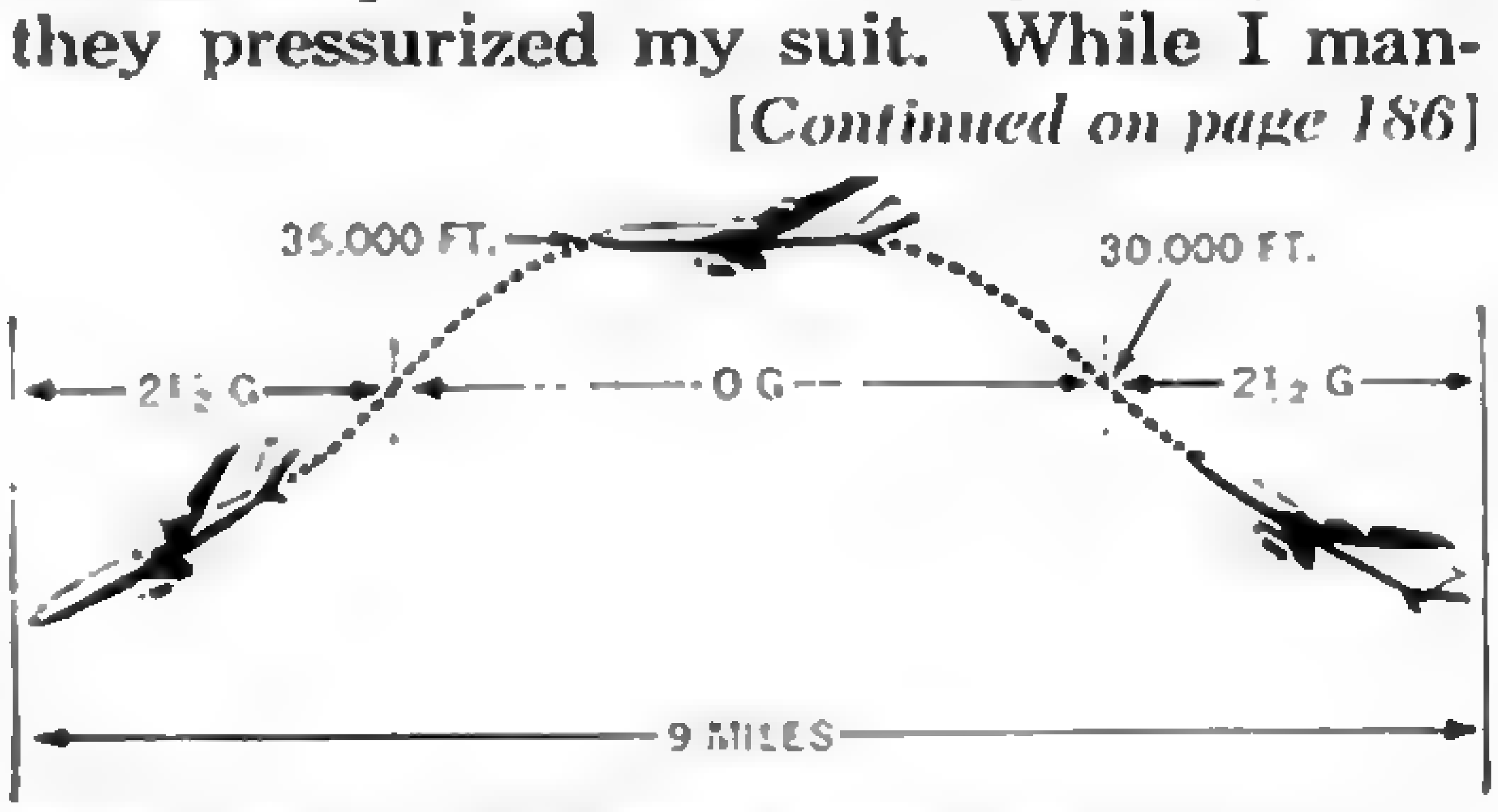
After the shirtsleeves bit came the space-suit exercise. Now, here I must explain that even in the dressing room, with the aid of two strong men, I had a hard time getting into the suit assigned to me. (No one told me whether the suit's configuration or my own was to blame, but I guess there *is* a difference between the average astronaut's waistline and mine.) At any rate, suiting me up in the plane proved a major undertaking. When they finally got the helmet over my head, I was bathed in sweat. But air circulation in the suit soon made me feel better.

Again I had some highly instructive zero-g flights. They gave convincing proof that a man floating weightlessly in a pressure suit is as helpless as an overturned turtle. He simply cannot do anything useful, without adequate foot and handholds or other devices to anchor him in front of his work station.

"Moon-walking." Beside zero-gravity flying, we had a few arcs at 1/6 of a g, the gravity on the surface of the moon. A bit to my surprise, I found walking in a pressurized suit easier at 1/6 g than at one g—although your "moon-walking" takes the form of a toe dance. Getting up after a spill seemed easier, too.

(In the dressing room, I'd had my attendants put me flat on my back, after they pressurized my suit. While I man-

[*Continued on page 186*]



Here's how KC-135 plane creates zero gravity. During its 30-second travel through a ballistic arc—the part of its course shown above the 30,000-foot level—the occupants of its cabin are weightless.

What It's Like to Be Weightless

[*Continued from page 82*]

aged to roll over on my stomach, I dismally failed to get up. Later on I learned that with practice one can "rock" himself up, using the elasticity of the pressure suit like a spring.)

But my curiosity was becoming dampened by another problem. With my mobility greatly reduced in the pressure suit, I had to stand upright during the 2½-g pullouts preceding the ballistic arcs.

Every time the pilot pulled out, I felt the blood drain out of my head. Then I felt it surge back up again.

And along with it came a dismaying upsurge of the contents of my stomach—which I managed to suppress only with the greatest difficulty, as the ups and downs went on. Now I understood why the Weightless Wonder had such an ample supply of cellophane bags aboard. But they were no help to a man in a space suit, an awkward place indeed to be seasick.

Don Griggs saw my predicament before it was too late and I was promptly depressurized and relieved of my helmet, restoring my well-being for the last few ballistic arcs. Nevertheless, I suspect I may have looked like one of those fabled "little green men from outer space," when I stepped out of the Weightless Wonder at the flight's end.

Water tanks vs. planes. Earlier I had tried a way of simulating zero gravity: underwater tests, by a space-suited astronaut weighted down to neutral buoyancy [PS, Feb. '68]. They are convenient and inexpensive, and have no practical time limit. Still, they are not quite the real thing. In a neutral-buoyancy tank, skin pressure always reminds you that you are not really weightless, but merely buoyed up. If you assume a head-down position, blood rushes to your head and the pulse in your temples quickly tells you which way is "down."

Short of actually going into orbit, then, true weightlessness for as long as a half-minute is possible only in the ballistic-arc airplane flights. A souvenir of my own is a certificate awarding me honorary membership in "The Society of Interplanetary Free Floaters" for "gross and flagrant violation of the irrevocable law of gravity while participating in aerial flight." PS

1969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Will Mighty Magnets Protect Voyagers to Planets?

Applying the strange phenomenon of "superconductivity" in space flight promises shields against deadly radiation, gyros without friction, and other innovations in travel beyond the earth

By
DR. WERNHER VON BRAUN
Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

Frictionless gyros, midget computers, magnetic shields against deadly radiation—these are among the aids to space flight promised by a newly exploited principle known as "superconductivity."

Imagine a wire with zero electrical resistance. A current in an endless loop of it, once started, would flow forever. Coils without resistance might be expected to carry huge currents, and make superpowerful magnets possible.

Actually, many metals' resistance does vanish, at a few degrees above absolute zero. Called superconductivity, this strange phenomenon has been known for 57 years—but, until recently, efforts to apply it in supermagnets failed. As if breaking a spell, a magnetic field destroyed a metal's superconductivity. Then, in the 1960s, metals were found that stayed superconductive even in intense magnetic fields—compounds of the silvery metal niobium with tin, zirconium, or titanium [PS, Mar. '67].

Superconducting magnets of these new materials have reached field strengths of 140,000 gauss, and 300,000 gauss is considered possible. For comparison, strong non-superconductive electromagnets rarely exceed 20,000 gauss. The earth's magnetic field is half a gauss.

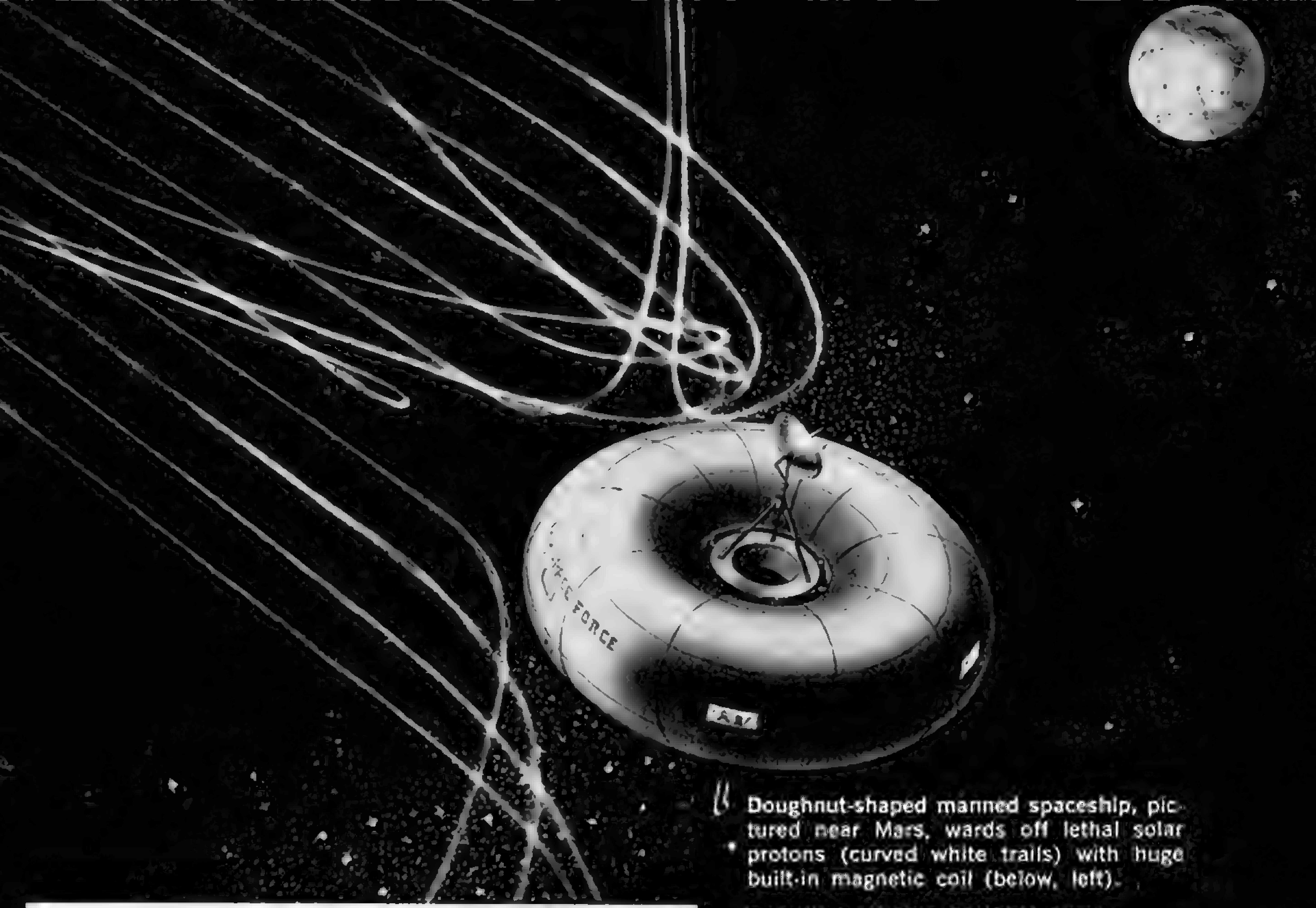
Comparatively light weight and low power needs make the new supermagnets and other superconductive devices attractive for applications in space:

Magnetic shielding. Safeguarding future interplanetary travelers from lethal radiation may well be the biggest-scale and most dramatic use.

Quite modest radiation shielding suffices for space ventures as brief as a week-long round trip to the moon. But a voyage of two or three years—say, to Mars—faces the hazard of "giant" solar flares occurring every few months. They will repeatedly bombard a spaceship with bulletlike protons, having awesome energies up to a billion electron volts. Successive exposures to this radiation could add up to a deadly dose.

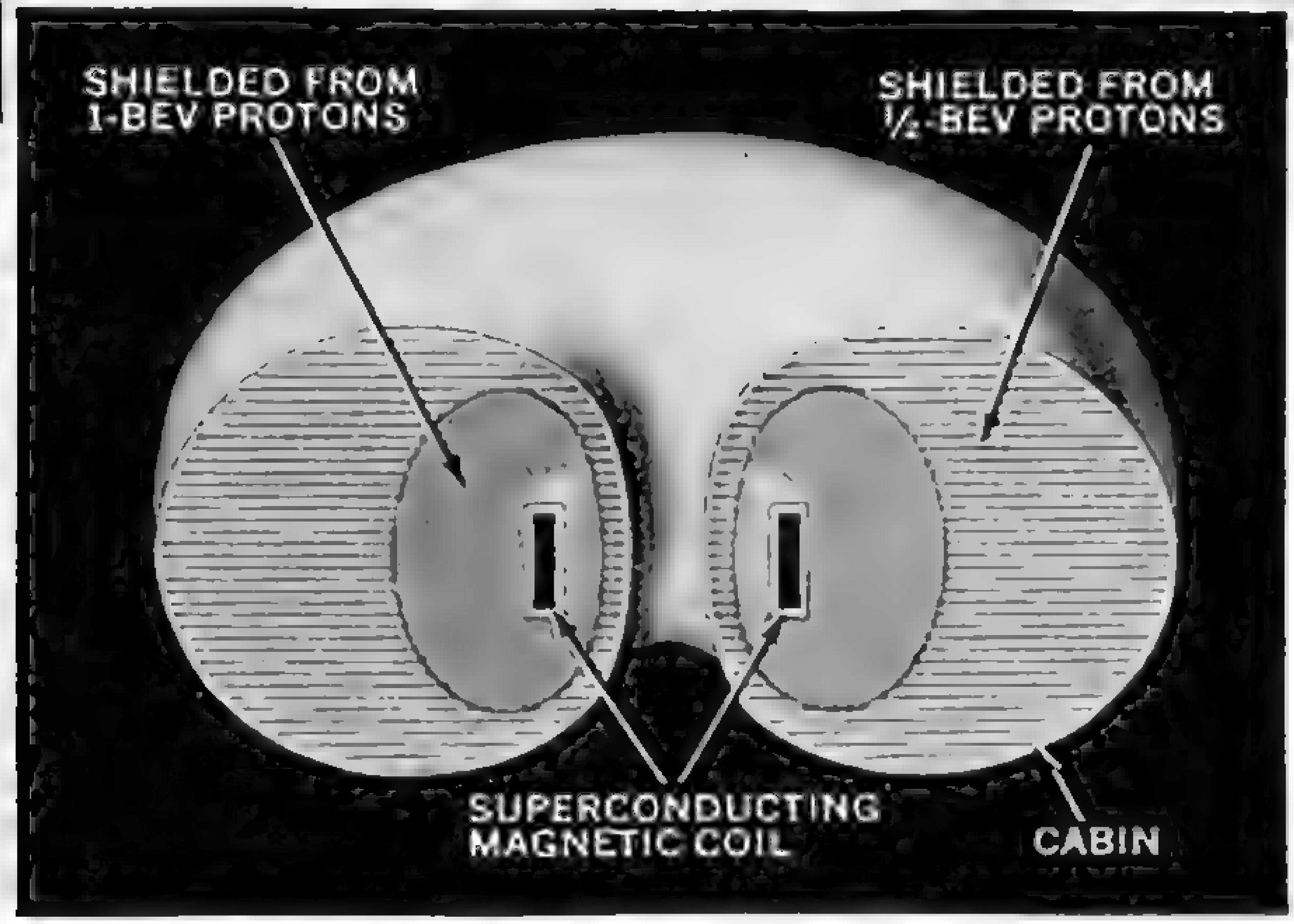
We could armor a cabin thickly enough to counter the peril with a shielding material such as carbon, water, aluminum, or polyethylene. But if we do, we find the sheer weight of this "passive" shield one of the biggest items of the load we are trying to rocket to a planet and back. To that discouraging problem, it looks now as if superconductivity offers the answer—"active" shielding.

A magnetic shield, wielding a mighty superconducting magnet, is envisioned in several active-shielding studies made for the Air Force and for NASA. Pictured here is one version, proposed by Dr. Sidney W. Kash and Robert F. Tooper of the IIT Research Institute, Chicago. Built into a doughnut-shaped spaceship is a 50,000-gauss superconducting magnet—a cylindrical solenoid of niobium-tin,

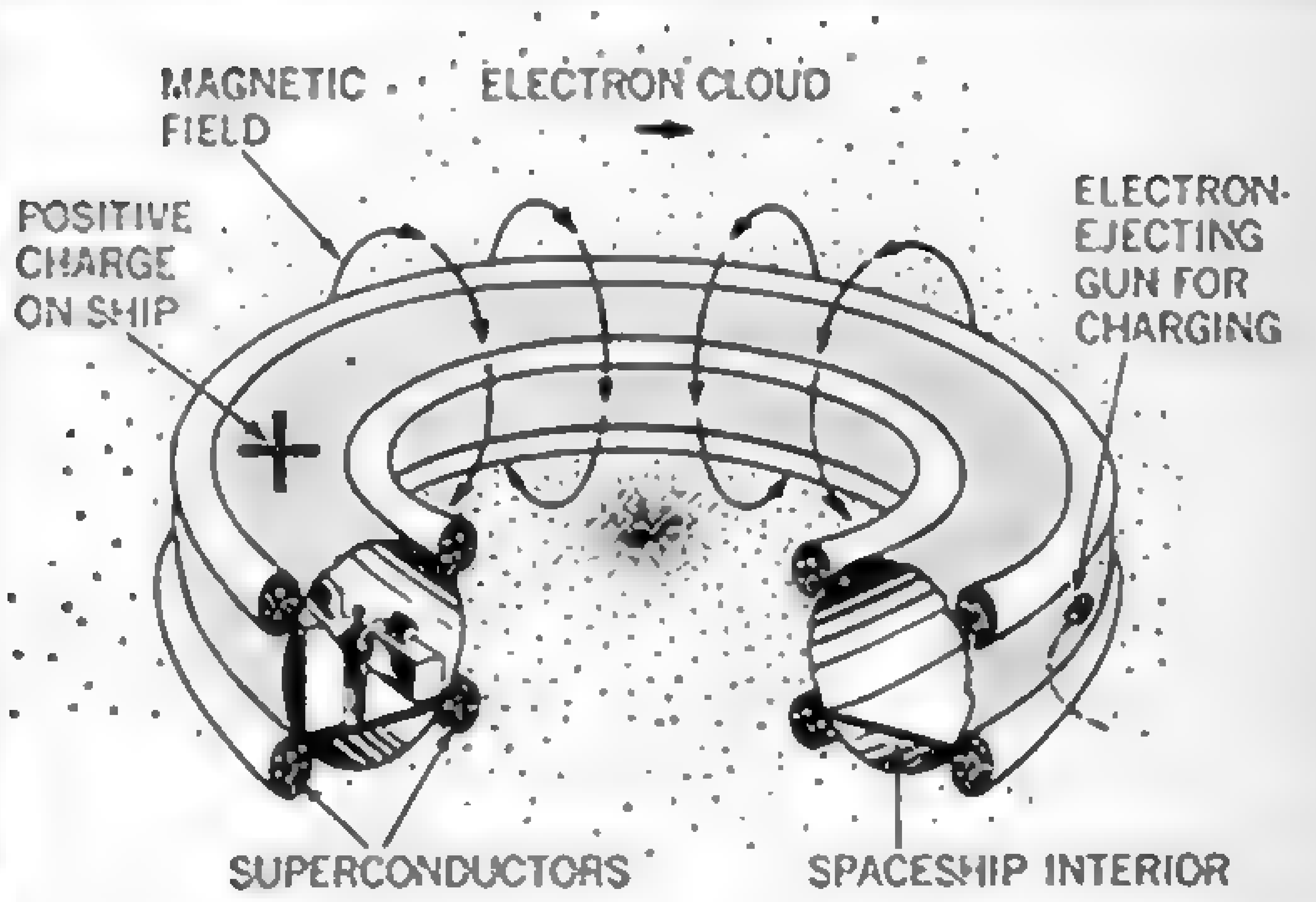


Doughnut-shaped manned spaceship, pictured near Mars, wards off lethal solar protons (curved white trails) with huge built-in magnetic coil (below, left).

DRAWING BY CHIP COKEING, IITRI



Sectional view shows magnetic shielding of pictured Mars spaceship, as envisioned by IIT Research Institute scientists. Superconductive magnet of 50,000 gauss could shield dark-shaded part of cabin (5,000 cubic feet) from protons with energy as high as one Bev, and rest from lower-energy ones.

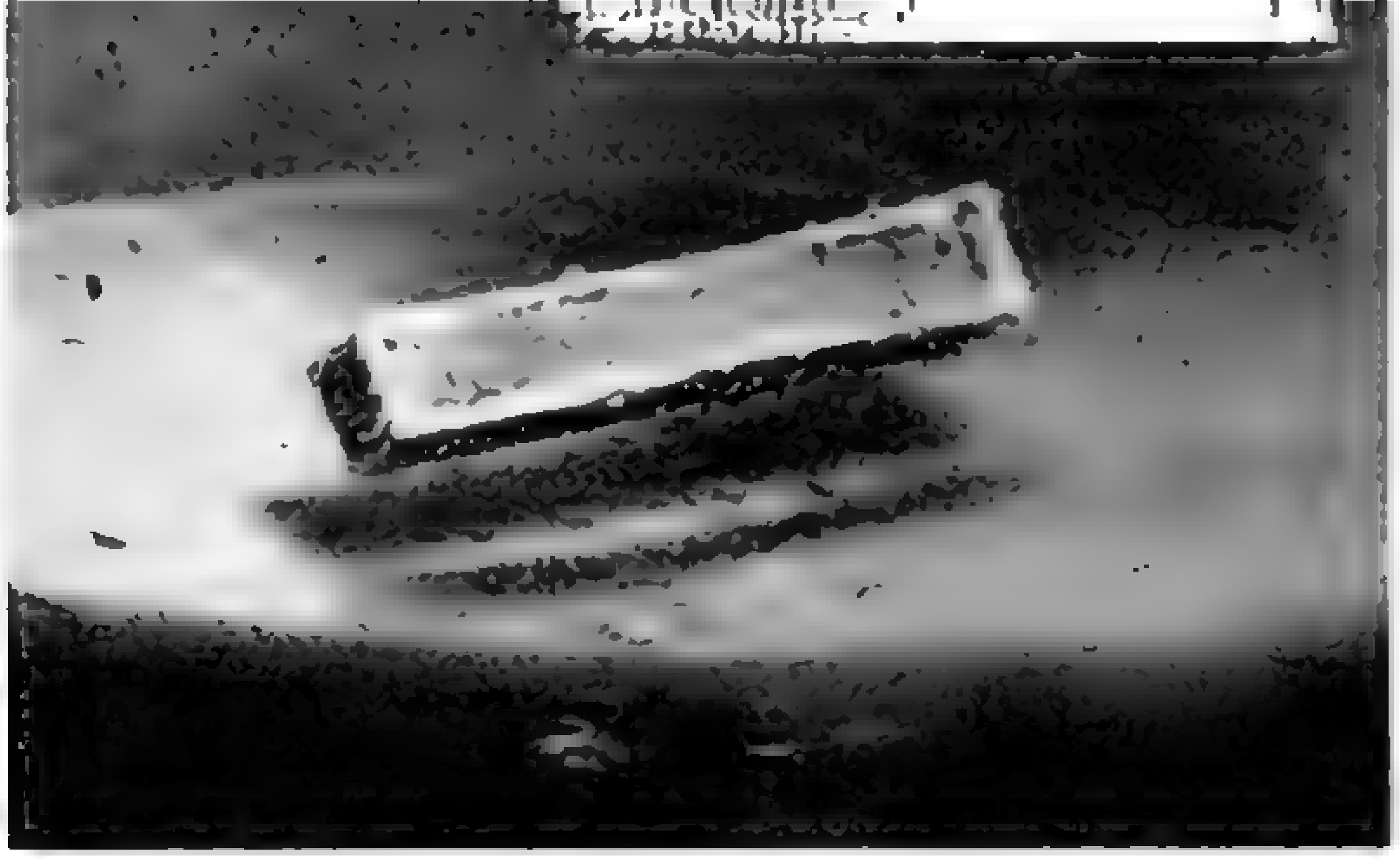


"Plasma shielding," an alternate plan, puts positive electric charge on craft to repel protons—and uses superconductive magnet's field to prevent approach of electrons that would destroy charge.

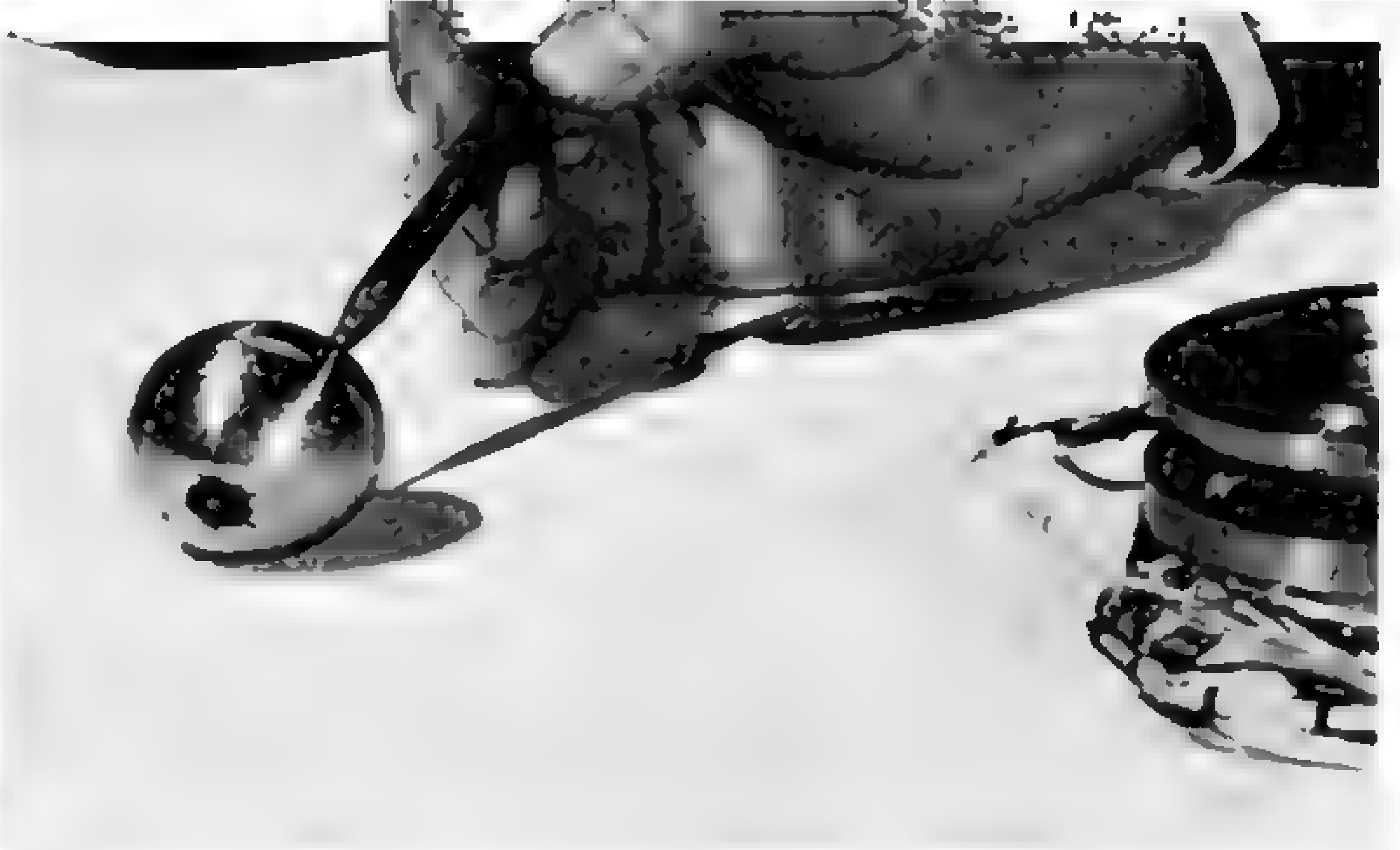
13 feet in diameter, kept chilled by a refrigerating system aboard.

Science-fiction writers are fond of imagining a "force field" that offers an invisible, impassable barrier against some menace. Here would be a real one. The potent magnetic field could deflect and ward off even the one-Bev protons of giant solar flares. In the Kash-Tooper study, the magnetic shielding would weigh about 10,000 pounds—compared to a million pounds of passive shielding, for equal protection.

The huge amount of energy stored in



"Levitation" is demonstrated by small bar magnet floating above superconductive lead dish, at NASA's Lewis Research Center in Cleveland, where much of NASA's advanced magnetics research is under way.



Gyro applies superconductivity. Golfball-size rotor of this experimental General Electric gyro spins without friction, supported solely by a magnetic field in a housing partly seen at far right.

a magnetic shield isn't something you put there just by flipping a switch. By one estimate, building it up might take 55 hours, using a 10-kilowatt power source (which the craft could then leave behind). So much energy in a coil could also be a weird hazard. Conceivably it could be disastrously released, melting or vaporizing part of the structure, if an accident destroyed the coil's superconductivity at any point. But designers see a way to play safe, by dividing the coil into many separate circuits.

"Plasma shielding." An alternative plan suggests a form of electrostatic shielding. If a spaceship's exterior could be kept positively charged, at a potential of some 300 million volts, that would repel the positively charged protons.

The catch is that negative-charged electrons in space, irresistibly lured by the positive charge, would flow to the ship and rapidly discharge it. Keeping it charged would therefore take a staggering 10 million kilowatts or so, nearly double the ultimate power of Grand Coulee! But a way around that, again applying superconductivity, is now seen:

Superconducting rings, encircling the ship, would create a magnetic barrier that attracted electrons couldn't cross. Instead, they would orbit around the ship in a cloud or plasma—for all the world like a circling swarm of voracious mosquitoes, eager to "bite" the craft (discharge it) but kept at a distance by its "Citronella" (magnetic field).

This "plasma shielding" should be even more weight-saving than "pure" magnetic shielding, says its proponent, Dr. Richard H. Levy of Avco-Everett Research Laboratory, Everett, Mass. A lower-strength magnetic field, probably less than 3,000 gauss, should prove sufficient.

Superconducting gyros. "Levitation" is made possible by certain superconducting metals' ability to act as a sort of magnetic insulator. They repel a magnetic field in such a way that the force will suspend an object stably in midair. This is strikingly demonstrated when a bar magnet, actually suspended on its own magnetic-field lines, floats above a superconducting lead dish cooled by liquid helium. (See photo.)

This magic-like principle of superconductive suspension has been successfully applied to gyroscopes. The floating gyro rotor, requiring no gimbals, spins without friction in a vacuum. Once brought up to speed, it runs for weeks with no further application of power. No eddy currents are induced in it, since the supporting magnetic field cannot penetrate it. Deflection angles are measured optically.

What results is a gyro many times more accurate than the best conventional ones. Its use may be foreseen, not only for missiles and missile-armed submarines, but also in space vehicles.

Computers for space. The propensity of many superconducting materials to "go normal" (lose their superconductivity) in a magnetic field has one useful and redeeming aspect. It permits their employment as contactless switching devices, called cryotrons. A cryotron consists of a thin-film "gate wire" and a "control wire," both superconductive. Send a current through the control wire, and its magnetic field kills the superconductivity of the gate wire, giving the effect of an on-off switch.

All basic types of electronic computers' circuits can be built from combina-

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Will Magnets Protect Space Voyagers?

[*Continued from page 100*]

tions of these microminiature switching units. The resulting computer, which is kept refrigerated in operation, is reduced to shoebox size and consumes extraordinarily little power—ideal qualities for space use. A cryotron computer and a superconducting gyro and accelerometer could make up a high-precision navigation system to help future astronauts find their way about the solar system.

More space uses for supermagnets. Suggested ways to apply superconducting magnets in space also include these:

- Magnetic docking may offer advantages over mechanical-coupling means.
- Forming a "magnetic window" in the hot plasma around a reentering spacecraft has been proposed, to avoid a communication blackout at that time.
- Magnetic braking could ease *g*-forces and heating during an interplanetary craft's high-speed entry into a planet's atmosphere. For the several minutes of the maneuver, a 10,000-gauss magnet could exert a substantial braking force, against an atmosphere made electrically conductive by the shock wave of entry.
- Ion and plasma space-propulsion engines under development, which use auxiliary magnetic fields, will have their performance improved by superconducting magnets. Ultimately they may draw their electric power from thermonuclear space-power plants, if efforts to harness nuclear fusion for power succeed; and superconducting magnets may aid the promising "magnetic-pinch" approach to that tantalizing goal.

The uncertain factor—man. Before astronauts take long journeys in magnet-using spaceships, we shall want to make sure whether prolonged exposure to intense magnetic fields could do them any harm. If so, we would have to keep the cabin relatively field-free; for magnetic shielding, such designs are available.

So far, not even experimenters with powerful magnets seem to have observed any untoward effects on humans. But more-intensive research, only lately begun with higher animals such as squirrel monkeys, is needed to settle the question beyond doubt. In these trials, superconducting magnets themselves should have an important part. PS

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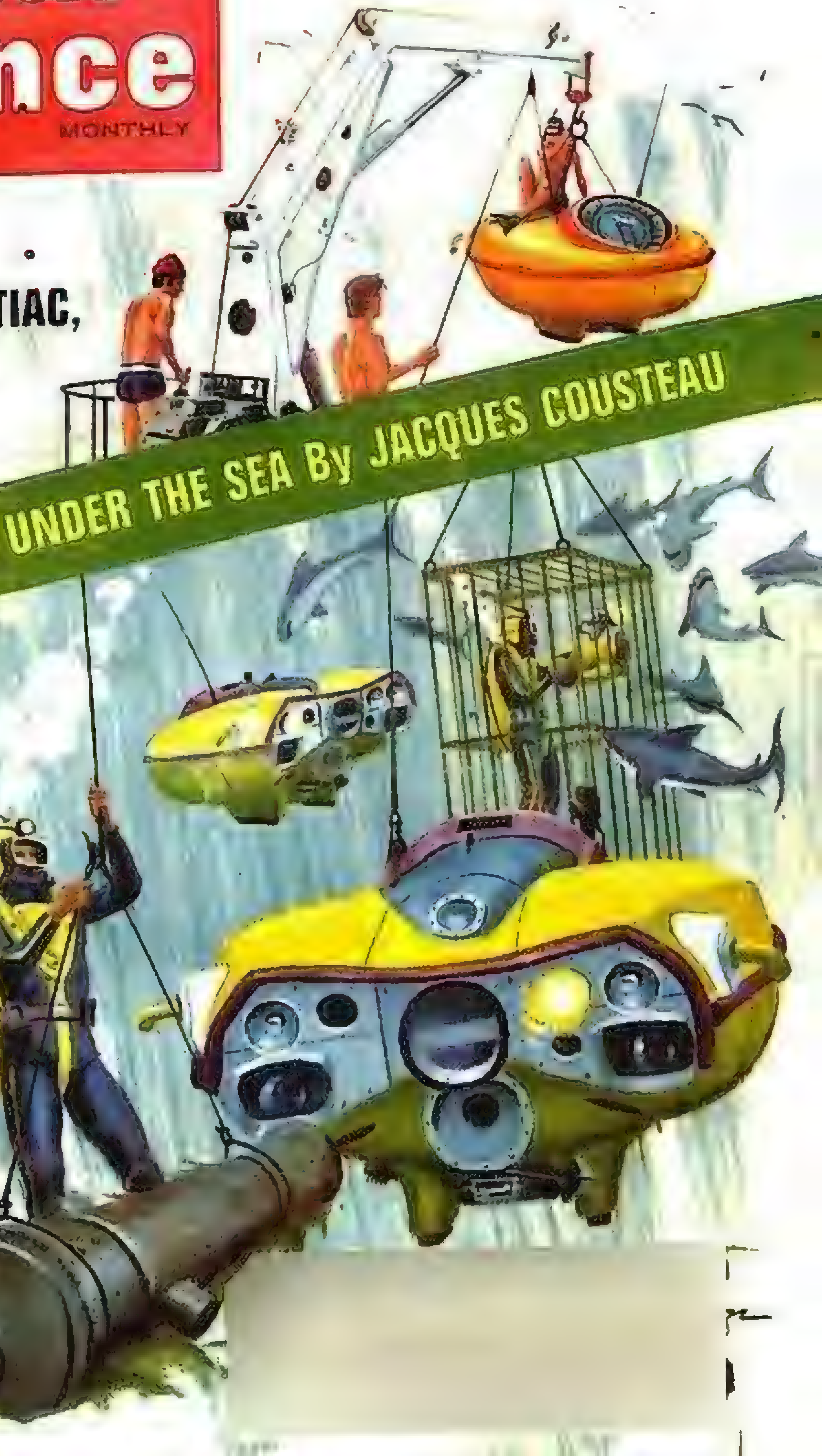


HOW WE FILM UNDER THE SEA By JACQUES COUSTEAU

16-Page Extra! SECRETS OF KEEPING YOUR AUTOMATIC WASHER TROUBLE-FREE

HYDRON: New Miracle Plastic— What It Can Do

SPECIAL BOATING SECTION

Lighter Than Aluminum ...Stronger Than Steel!

Exotic new composite materials of the Space Age—built around filaments of boron and graphite, and crystal "whiskers"—promise a magic carpet for aerospace designers

Whiskers promise ne materials of fantast strength. Here are whisk ers of silicon carbid made by Carborundur Co.—bonded in plastic readily removable b heat, for easy handling

By DR. WERNHER VON BRAUN

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

Ever since Explorer I, our first satellite, the Space Age has stimulated a search for materials that are stronger, stiffer, lighter, and usable at higher temperatures than any before. From this quest is now evolving a family of extraordinary structural compositions—lighter than aluminum and stronger than steel.

Collectively they are called "fiber-reinforced composite materials." In other words, to make them, high-strength fibers of one substance are embedded in a matrix of a different substance.

This idea has been demonstrated before by the success story of fiberglass—whose strong but brittle glass fibers impart their strength to a protective matrix of epoxy resin. Into the new composite materials, however, go far more exotic substances than glass:

Strength-adding ingredients include filaments of boron or graphite, and "whiskers"—needle-shaped

single crystals—of metals or ceramics. Either a resin or a metal can serve as the matrix.

What can we do with them? Breathtaking possibilities await the full development of these advanced materials:

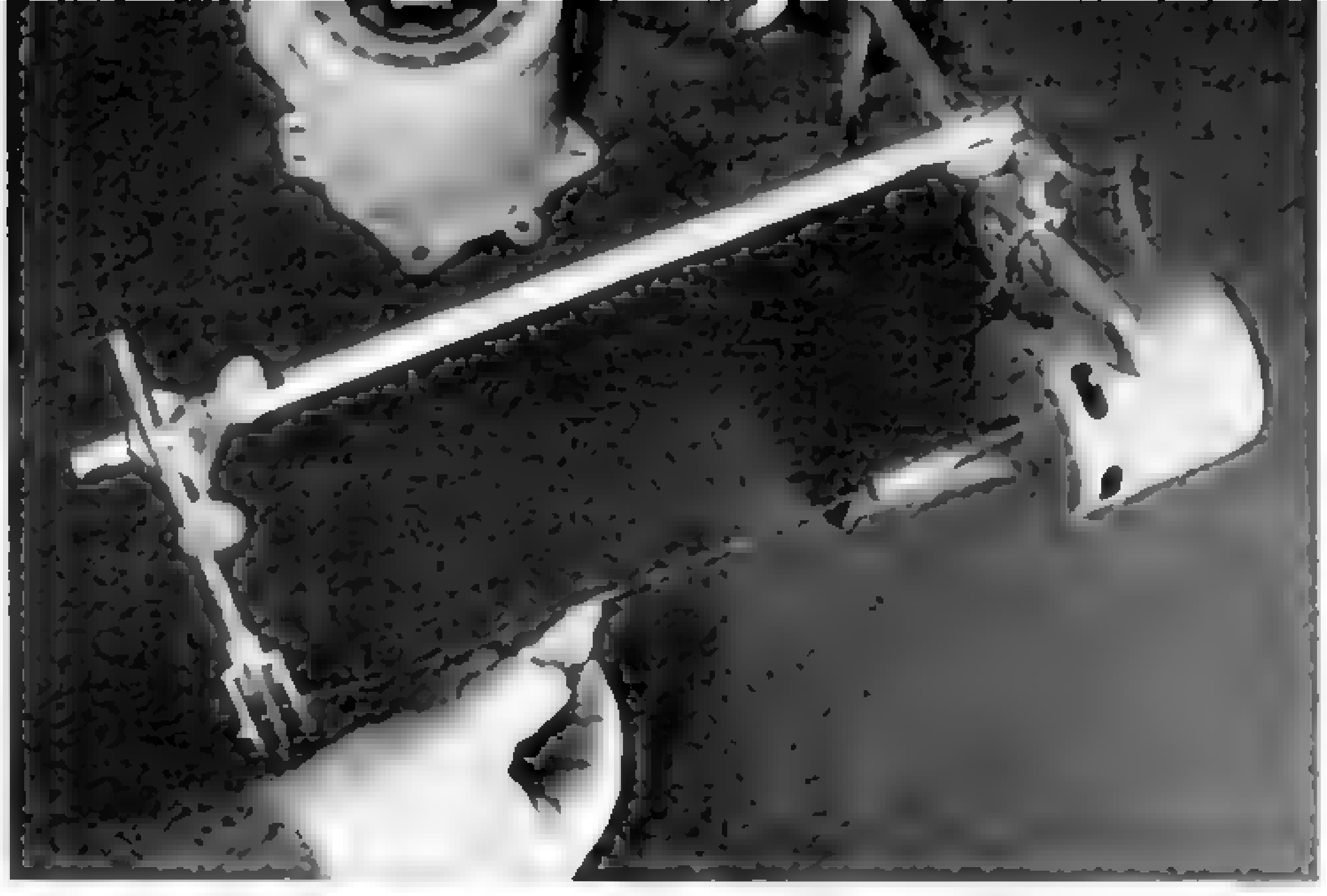
They could make possible a skyscraper a mile high—or a suspension bridge twice as long as is feasible today.

In military and commercial aircraft, predictable results of their use appear revolutionary. By making wings and fuselage of the new materials (instead of aluminum and other metals), the structural weight of an airplane may ultimately be reduced by as much as a third. Just a 15-percent reduction, Northrop engineers conservatively calculate, would enable a high-performance military jet to fly 10 percent farther or carry 30 percent more ordnance on the same amount of fuel. Its takeoff would be 15 percent shorter; its rate of climb, 10 percent faster.

Other likely uses are in space vehicles, deep-diving structures, solid-propellant rocket cases, jet turbine blades, and nuclear power plants.

The first hardware. Boron and graphite composites are the first of the exotic materials to reach the form of actual hardware for trial.

For aircraft, a boron-and-epoxy-resin composite has been made into a rudder, a landing-gear door, a flap, and horizontal stabilizers. Due next, on the way to whole airframes, are a landing-gear strut, helicopter-rotor blades, and a "wing box," the major load-bearing segment of an advanced swing wing.



Mechanical whisker-spinner, developed in study for NASA by General Technologies Corp., turns whiskers (from hand-held wad) into yarn. Combining yarn with matrix of metal or resin gives superstrong material.

Jet-engine turbine blades with grown-in whiskers are made by United Aircraft Corp. process called "unidirectional solidification." These heat-resisting cobalt-base blades are latest product of method.

Pure boron, a chemical element lighter than aluminum, is a brownish crystalline substance. Depositing it from its vapor on hot and thin tungsten wires yields the boron filaments in the resin-composite hardware. By drawing close-packed boron filaments through a molten-magnesium bath, a NASA contractor has also produced boron-magnesium rods, which are called "immediately" capable of providing structural members for space vehicles.

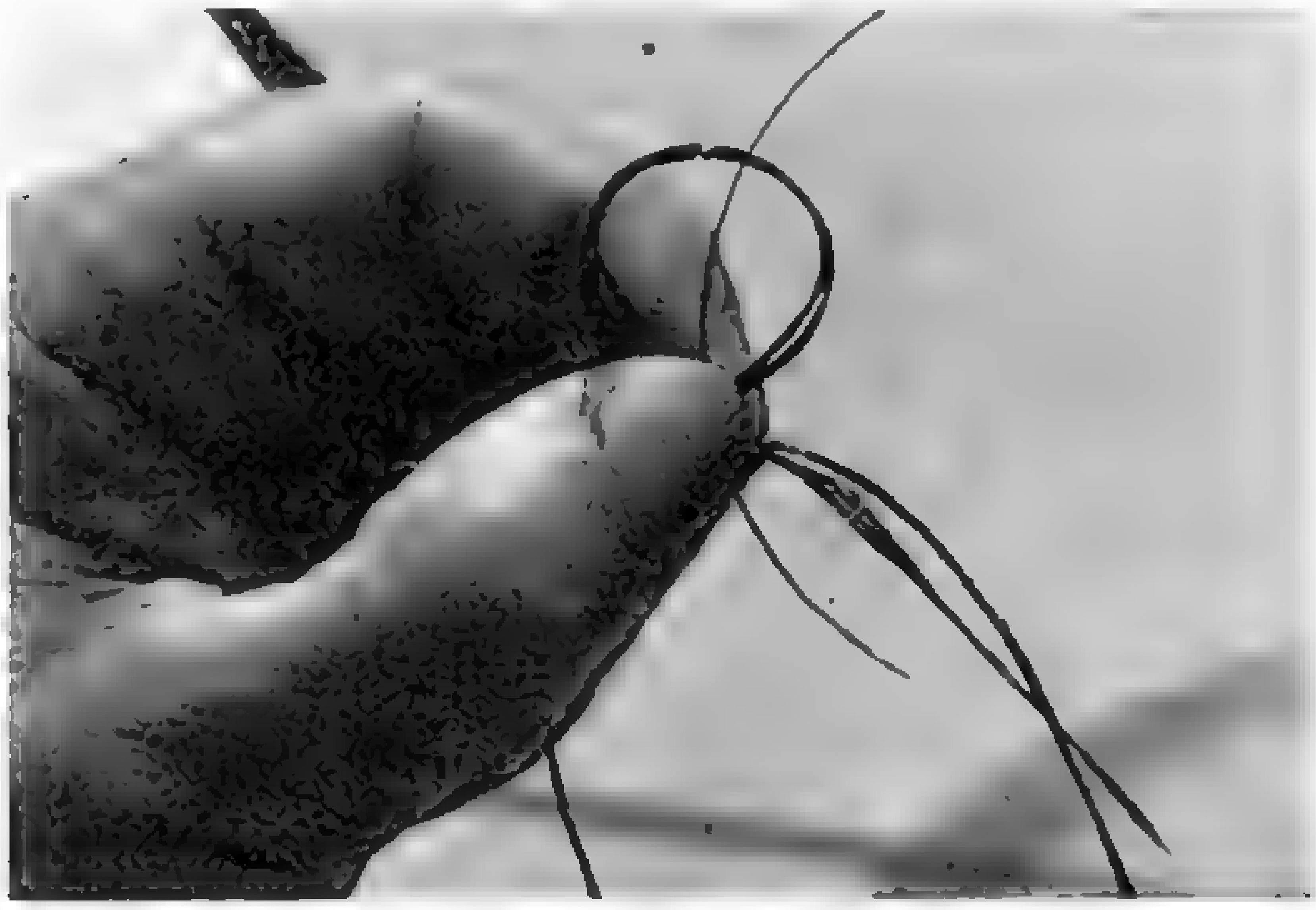
A promising and less-expensive rival of boron has lately appeared in the form of high-strength, lightweight filaments of graphite, obtained by heat treatment of rayon or other fibers. Test hardware of graphite-and-resin composites now is getting flight trials, too.

So novel are these structural materials that many steps in producing them resemble textile-making more than metallurgy. Another departure is that the reinforcing fibers can be oriented to give greatest strength in one direction, for a structural member stressed mainly in that direction. These observations apply equally to whisker materials.

Whiskers—best of all. For a decade it has been known that whiskers will make the best reinforcing fibers of all, especially for use at high temperature.

The story of whiskers began when mysterious short circuits in electrical equipment were traced to tiny metallic strands that sprouted spontaneously from metal terminals. Discovery of the amazing

Leading-edge section of graphite composite, twice as strong as steel but 40 percent lighter than aluminum part it replaces, goes on F-5 fighter wing for successful trial. Shiny half of it is nickel-coated.



These graphite filaments, made by intense-heat process from rayon threads, are combined with epoxy resin, wound on mandrel, and cured by heat and pressure to form graphite-composite parts.

Landing-gear door of boron composite, 29 percent lighter than usual aluminum door, meets test on F-5. Skin is of bonded layers of epoxy-resin type containing hair-thin tungsten wires coated with boron.

strength of these whiskers, and also of nonmetallic ones, followed.

The strength of whiskers such as those of sapphire (alumina) approaches the magnitude of interatomic forces—which, in theory, set the limit of stress a material can take without being pulled apart. In practice, familiar structural metals come nowhere near this theoretical strength, because of imperfections in their crystal structure. But the tiny diameter of whiskers, on the order of 1/25,000 of an inch, minimizes the likelihood of imperfections in them.

For researchers on whisker materials, silver serves well as a "model" matrix. In trials at room temperature, silver containing 10 to 15 percent of sapphire whiskers by volume ruptured at 63,000 pounds per square inch (p.s.i.), compared to 17,000 p.s.i. for pure silver. At 1,400 degrees F. it still withstood 44,600 p.s.i.; the silver, a mere 2,000. Even at 1,720 degrees, just 40 short of silver's melting point, the whisker material retained a tensile strength of 25,000 p.s.i.

Such phenomenal gains in strength are by no means limited to sapphire whiskers. Among promising ones are whiskers of boron carbide, beryllium oxide, silicon dioxide, and silicon carbide (an abrasive trade-named Carborundum).

There is also a wide choice of matrix materials. Particularly significant for the weight-conscious designer of aerospace vehicles is the resulting strength-to-density ratio—which is successively higher for sapphire whiskers in silver or nickel, in aluminum, and in epoxy. We see that whisker-reinforced epoxy resin looks awfully attractive, at least at moderate temperatures.

What are we waiting for? Why don't we start using whiskers on a big scale? The answer is that they offer a classical example of a promising idea that takes years of applied research to put into industrial practice.

While whiskers still are costly ($750 to $10,000 a pound), making them is not too difficult. They can be grown in furnaces by condensing their vapor on a graphite base, and in other ways. As desired, they can be coarse or fine, curly or straight. They range from a few hundredths of an inch up to inches long; a handful of them

[*Continued on page 202*]

"50 bucks until payday, please?"

One of those money machines reported in use abroad has made an appearance in Florida. The holder of a credit card from the Capital National Bank, Miami, can insert his card and instantly borrow $50 from the machine in the lobby.

Flying platform tied to truck

This whirlybird skyhook, made by Dornier of Germany, carries 120 pounds of TV, radio, or photographic gear to an altitude of 1,000 feet. A small gas turbine on board compresses air for the rotor-tip jets. The truck pumps fuel through the tethering hose and regulates altitude with a powered reel-winding drum.

Composites . . . Stronger Than Steel

[*Continued from page 100*]

may look like a ball of cotton or wool. Silicon carbide whiskers have lately become available by the ton, and some others by the pound.

But putting the whiskers into materials is something else again. Only now are solutions to some of the many problems beginning to appear.

You would like a composite material to contain a sizable proportion of whiskers—but they are contrary things to work with. Oriented at random like broomsticks in disarray, they may make up less than a fifth of the volume they fill. Try to pack the crystals closer by brute force, and they break. The alternative is to try to coax them into orderly alignment, side by side. One possible way is to spin whisker "wool" into a yarn, to be woven into a mat.

How to make "whisker yarn" was recently demonstrated on a miniature scale in a study for NASA at General Technologies Corp., Reston, Va. A motor turned a wire bearing a drop of adhesive at one end. By touching a wad of silicon carbide whiskers to the adhesive and drawing it along the wire, a whisker yarn was spun. The method, reported the researchers, could be scaled up for mass output by using textile-type machinery.

Grown-in whiskers. One short cut to whisker materials has been found. By casting an alloy in a mold, and withdrawing heat in one direction, researchers at United Aircraft Research Laboratories have succeeded in growing reinforcing whiskers right inside some metals. In others, the process has produced reinforcing platelets, or "lamellae," almost as good as whiskers. The scheme works with only a limited number of alloys—but among these are heat-resisting ones, from which experimental turbine blades for jet engines have already been made.

What comes next will be exciting to watch. In all the millennia since the Bronze Age, the strength-to-weight ratio of structural materials has been little more than doubled; suddenly, the new composites make it look possible to triple the ratio. And they come at a time when, to meet space objectives, the properties of conventional materials have been taxed to the practical limit.

MARCH 1969 60 CENTS

Popular Science

MONTHLY

What the Apollo 8 Moon Flight Really Did for Us
By WERNHER VON BRAUN

What Close Calls Do to Your Driving

Now: Canned Movies on Your TV Set

Stop! 16-Page Special:

BRAKES FOR YOUR CAR

POWER-TOOL PROJECTS:

- New Ways to Add Shelves All Through Your House
- A Great Redwood Camper You Can Build

The Growing Rage for FUN CARS

Man's first voyage to the moon

This is it! Pictured climax of daring expedition by three astronauts in Apollo 8 is firing of rocket engine to start home—for its failure would have marooned them in lunar orbit, beyond hope of rescue. Launched into earth orbit and then to moon by mighty Saturn V, craft has first rocket-braked itself to circle moon—making crew the first men captured by another celestial body's gravity. Homeward journey, completing gigantic figure-8 path of nearly half a million miles, ends in first manned reentry ever made at back-from-the-moon speed of almost 25,000 m.p.h.

What the Apollo 8 Moon Flight Really Did for Us

By DR. WERNHER VON BRAUN
Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

Our first manned expedition to another world, by performing a series of unprecedented space feats, has brought about the possibility of setting foot upon the moon this summer

"The moon is essentially gray. Looks like plaster of Paris . . . Langrenus is quite a huge crater . . . a central cone . . . walls are terraced . . . Bill and I are sharing the rendezvous window . . . We're just about over Messier and Pickering right now . . ."

Men had voyaged to the moon. Apollo 8 was in lunar orbit—and James A. Lovell Jr., Command Module Pilot and navigator, was telling what the crew saw. His companions were Frank Borman, Commander, and William A. Anders (a "Lunar Module Pilot" without a moon-landing Lunar Module), acting as photographer. The courageous astronauts' safe return, last Dec. 27, capped a fantastic space feat.

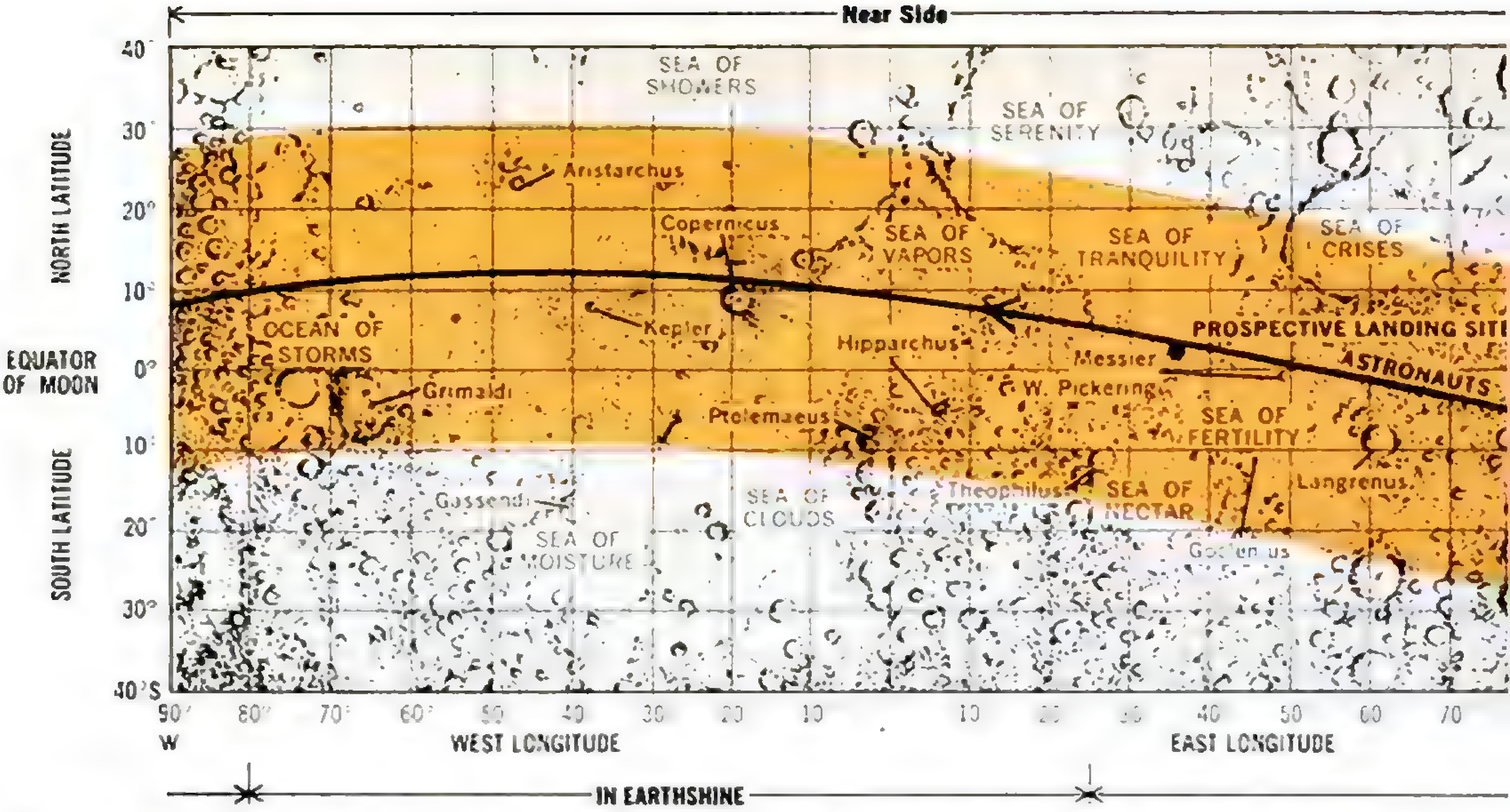
What did Apollo 8 accomplish, besides thrill-

Continued

HOW ASTRONAUTS VIEWED THE MOON FROM 70-MILE HEIGHT

Drawing of Apollo 8 spacecraft, cut away to show an astronaut at a window, is superimposed (in nose-down observing attitude in which it orbited moon) on superb Apollo 8 photo of scenery on moon's far side.

◀PAINTING BY BOB McCALL



Where Apollo 8 crew explored the moon

Colored band on PS-exclusive map marks region of moon, about 750 miles wide and 6,790 miles long, within extreme range of sight from spacecraft circling at 70-mile altitude. Wavy black line at its center is path of craft, in orbit inclined 12 degrees to lunar equator. Crew saw part of visible belt in

ing the world with the highest of high adventure? It took key steps toward a manned lunar landing—and their complete success was reflected in immediate announcement by NASA of what comes next and when:

Apollo 9—the first manned test of the Lunar Module, in a 10-day earth-orbiting mission tentatively set for a Feb. 28 launch—should be under way by the time this is read. Subject to its success, Apollo 10, this spring, will make a second voyage to the moon—where, this time, astronauts in the Lunar Module are to skim within 10 miles of the surface.

If all has gone well thus far, the actual landing can be attempted by Apollo 11 this summer. Gemini veterans Neil A. Armstrong, Edwin E. Aldrin Jr., and Michael Collins are to be the crew.

In preparing the way to the landing, all preceding missions will have played essential roles—and that of Apollo 8 was made clear by NASA beforehand:

What Apollo 8 set out to do. These were announced to be the mission's aims:

- To boost the first crew with the mighty Saturn V moon rocket.
- To pioneer starting a manned spacecraft on a trajectory to the moon.
- To test the Apollo radio system and its navigation system at lunar distance.
- To put a manned spacecraft into lunar orbit—thus practicing a maneuver indispensable to the moon-landing plan.
- To observe and photograph lunar landmarks usable for guidance.
- Also, among numerous other things, to gain practical experience in making midcourse corrections, controlling the spacecraft's interior temperature, using the onboard computer, and supporting a lunar mission from earth.

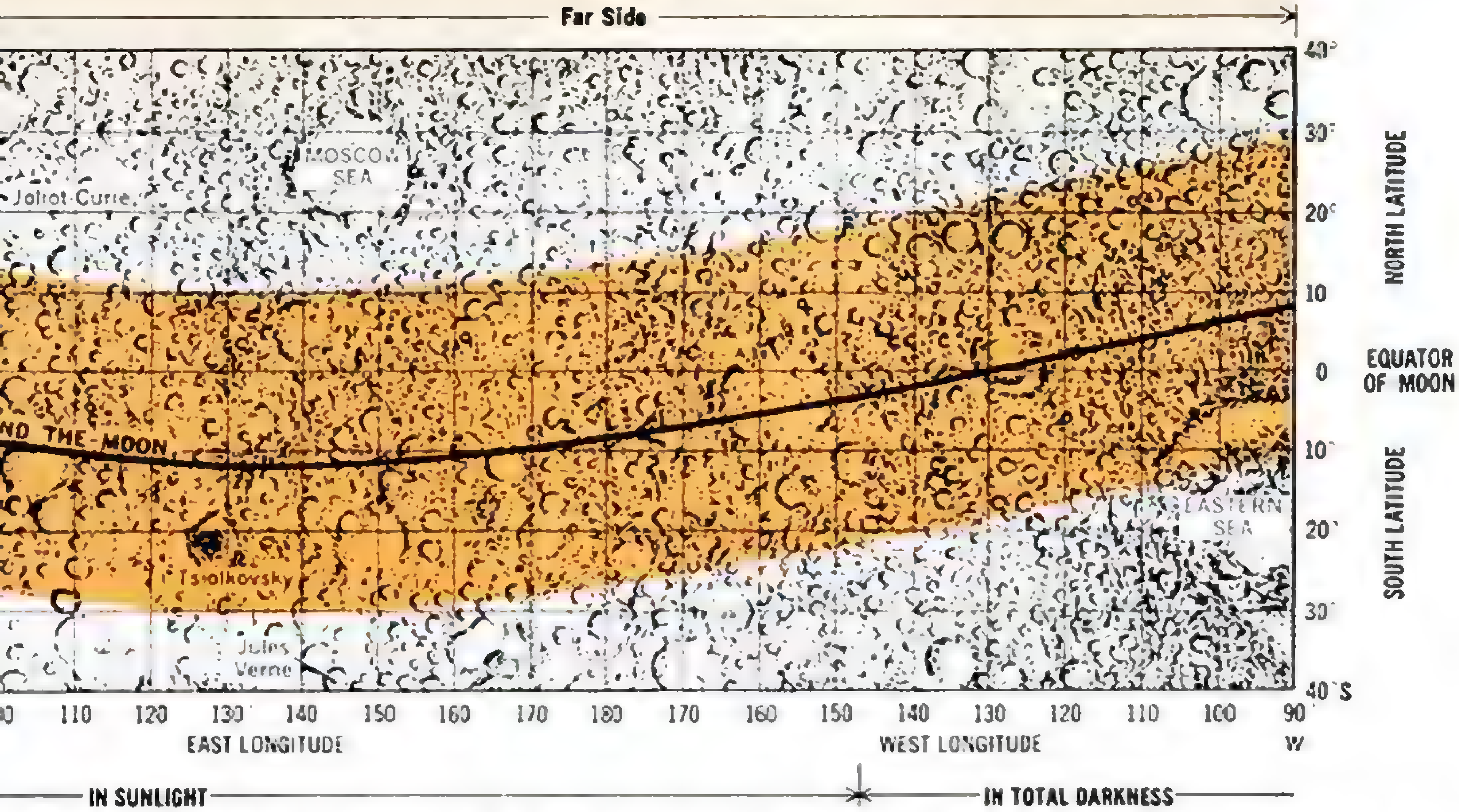
How well Apollo 8 accomplished every aim may best be seen from its story:

A perfect launch. Precisely on schedule at 7:51 a.m., Dec. 21, the towering white Saturn V shook the earth with its blast as its 363-foot-high bulk rose from Complex 39A at Cape Kennedy. Apollo 8—takeoff weight, 6,218,558 pounds—was on the way to the moon.

Into an earth-circling "parking orbit" at almost exactly the intended height of 119 statute miles, the Saturn V put a 142-ton space vehicle consisting of Saturn V's top stage (S-IVB), its Instrument Unit, and the manned spacecraft in the nose, made up of the conical 11-foot Command Module and the cylindrical 22-foot-long Service Module.

Go or no-go? Now came the first of a

ment upon adoption by International Astronomical Union in 1970



full sunlight of lunar day. Much of rest, though in lunar night, could be glimpsed by earthshine (reflected light from earth). From their preflight homework, astronauts recognized prominent craters at sight. They viewed a prospective landing site early in lunar day when long shadows showed up relief best. Mercator-style map, going clear around moon, shows central zone of both near and far sides.

series of decision points—whether to commit Apollo 8 to head for the moon. For the astronauts' safety, this and subsequent major steps would be taken only if tracking and telemetry showed all was well with crew, spacecraft, and the Saturn V's third stage. To the crew, everything looked fine. As Apollo 8 circled the earth once and part way around again in its parking orbit, NASA's Mission Control Center at Houston carefully evaluated its own telemetry records. Finally, the crucial decision was made:

"Apollo 8, you are go for TLI." That was short for "translunar injection," the start toward the moon.

What looked like a blazing white comet streaked across the night sky over Hawaii, trailing silvery spray. The crew had reignited Saturn V's 230,000-pound-thrust third-stage engine—and its burn of more than five minutes raised their speed from some 17,400 to 24,200 m.p.h., enough to enter a moonbound trajectory.

Traveling faster than anyone had before (and they would return at even higher speed), the crew quickly passed the 851-mile mark for the greatest distance man had ever ventured from earth, set by Gemini 11 in 1966. They would go hundreds of times as far to reach the moon, 220,000 miles from the earth at the time.

With Saturn V's duty flawlessly done, the spacecraft separated from its top stage and its sophisticated guidance unit, 20 minutes after translunar injection. The

[*Continued on page 220*]

Apollo 8 photograph with long-focus lens, looking south, reveals minute details of 40-mile-wide crater Goclenius (in foreground) and of others beyond it.

What Apollo 8 Moon Flight Did for Us

[*Continued from page 71*]

discarded stage, by dumping its residual propellants, was to propel itself past the moon's trailing edge and on into a permanent solar orbit. Spewing fumes, it hung a few hundred feet away, looking like a "furious white elephant" to Borman and pointing too close for comfort. He fired up the small spacecraft thrusters to get out of its way. (The first two spent stages, never in orbit, had fallen in the Atlantic.)

In the spacecraft, coasting now on a 66-hour journey to the moon, the crew doffed their pressure suits—and enjoyed the comfort of simple lightweight coveralls for the rest of their trip.

Behind, the world shrank. "I can see the entire earth now out of the center window," Borman reported from 30,000-mile distance. The crew made a slight midcourse correction, with the 20,500-pound-thrust Service Module engine.

As if going upgrade, the coasting craft was slowed by the earth's tug to about 2,200 m.p.h. before reaching the point, 38,900 miles from the moon, where lunar gravity took over. Then the moon's gravity, pulling the craft "downhill," speeded it up again to more than 5,700 m.p.h. A final midcourse correction was made with the craft's small thrusters (miniature rocket engines).

The moon itself, in its orbit around the earth, was sweeping along at 2,287 m.p.h. Past its leading edge scooted Apollo 8 like a car beating a locomotive to a railroad crossing. But the Apollo could not see the moon's rapidly growing bulk during this encounter, because its leading edge was not lit by the sun. "It was like a GCA [ground-control approach] with a 200-foot ceiling," Borman commented later. "All a pilot can do is have faith in his ground controller."

The most fateful decision. Nearly an hour before, it had been decided to commit the spacecraft to a lunar orbit.

Until then, the crew were assured of returning automatically to earth. If they lifted not a finger, the moon's gravity would swing them around it and head them homeward. But this "free return" had to be relinquished if lunar-orbiting power maneuvers were to be rehearsed.

Apollo 8 swung behind the moon, and out of radio contact with earth. The craft

What Apollo 8 Moon Flight Did for Us

urned hind end forward, and its engine ired for more than four minutes, braking ts speed to about 3,600 m.p.h. It was in unar orbit—initially an elliptical one, rom about 70 to 195 statute miles above he moon. As the astronauts began their hird circuit, they fired the engine again or 9½ seconds, making their orbit circuar at 70-mile height.

What the astronauts saw. Ten times the raft circled the moon, each circuit takng two hours. For the astronauts, those 20 hours were busy indeed.

A prospective Apollo lunar-landing site n the Sea of Tranquility, and landmarks or approaching it, drew their special atention. You couldn't miss it, they reiorted. Easily they spotted a certain tringular mountain and other promising uides seen before only on photographs rom unmanned spacecraft.

They took still photos and movies of heir own—which, because these could be rought back, excelled in quality even he magnificent moon pictures televised y our Lunar Orbiters. They examined lozens of "targets" of special interest—nd shared with stay-at-homes their view f the moon's scenery, in two of the voyge's six telecasts.

As they talked with Houston, voices ame loud and clear across nearly a quarer-million miles—a distance that radio vaves took 1¼ seconds to span, as gaps etween messages showed. Performance f the two-way communication hookup, ital for transmitting data and instrucions, surpassed even its engineers' hopes.

Then came what was probably the most ritical maneuver of all. On the moon's ar side, the crew fired up the spacecraft ngine to break free from lunar gravity. Had it failed, they would have been opelessly marooned in lunar orbit. But ts perfect burn, of more than three mintes, boosted their speed past the moon's ,328-m.p.h. escape velocity—and they vere homeward bound.

Coming back. Only one midcourse corection, with the small thrusters, was eeded on the 58-hour coast back to arth—which was comparatively uneventul until its final moments.

As Apollo 8 neared earth its speed eached about 24,700 m.p.h. Jettisoning

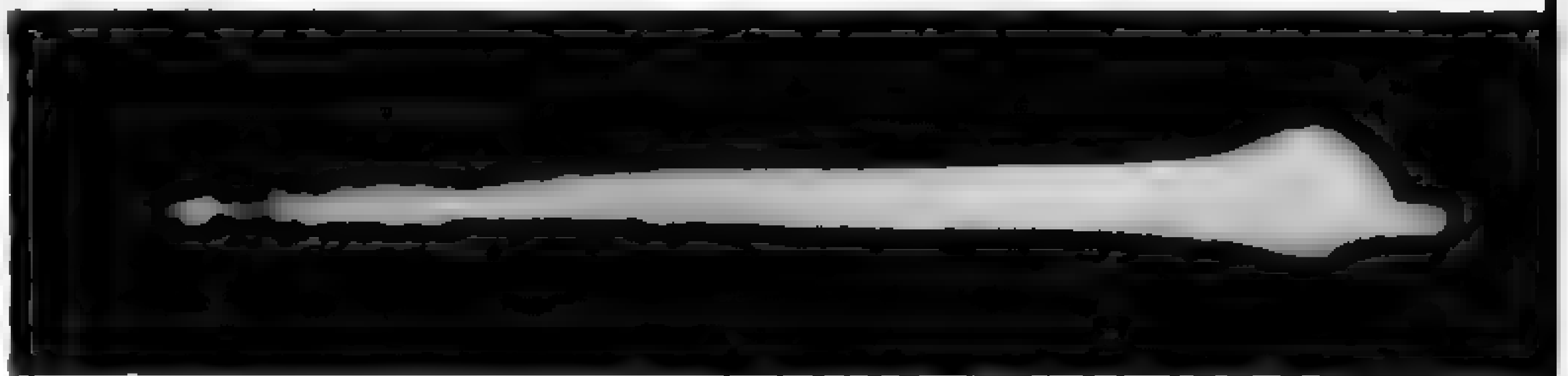
Continued

the Service Module to fiery distructio the manned Command Module plunge into the atmosphere at a shallow slan Instead of a dual-pulse "skip" entr planned earlier, it had been decided to s the spacecraft's automatic re-entry-guid ance system for one continuous descent steadily downward, except for two min rises along the way.

(The Apollo Command Module trimmed in such a fashion that it seeks a angle of attack of approximately 30 de grees. This creates a lift force at righ angles to the drag force. During the in tial phase of reentry the lift force acte upward, gradually leveling off the de scent. When the spacecraft began to ris again, its autopilot—acting on tangentia control thrusters—rotated it 180 degre so that the lift force acted downward.)

This descent strategy would keep th heat shield's temperature within an ac ceptable figure, nearly 5,000 degrees. Th cabin temperature, a comfortable 77 to 7 degrees throughout the voyage, was pu posely lowered to 61 degrees.

A tracking plane at 40,000 feet caugh the spectacular photo below of Apollo 8 flaming reentry.



Then Apollo 8's parachutes blossome out, one hour before dawn, and the cre readied itself for a "gentle plop" into th water like Apollo 7's. But it seemed tha the waves of the Pacific Ocean had faile to take instructions from Mission Contro Apollo 8 hit the water as if it were strikin a brick wall.

The crew was doused by half a gallo of salt water entering through the ven stack, and for an instant it looked as i their return from the moon would be te minated at the bottom of the sea. Th spacecraft capsized and had to be righte by the righting bags. But the crew ha come down to a pinpoint landing withi some 5,000 yards of the recovery carrie Yorktown, and soon the carrier had as tronauts and spacecraft safely aboard.

Apollo 8, mission accomplished, ha taken man on his first historic voyage t another world.

APRIL 1969 50 CENTS

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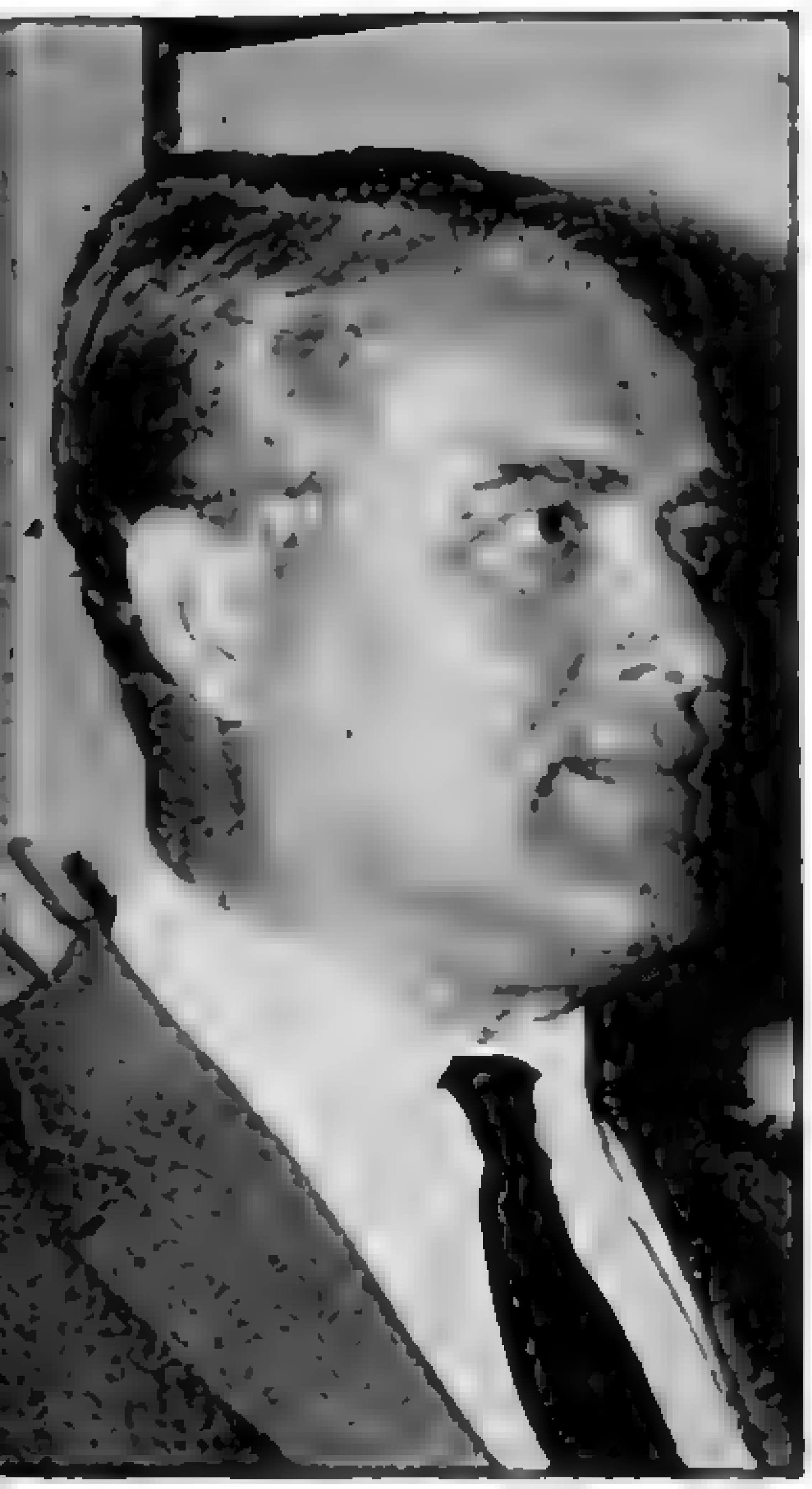
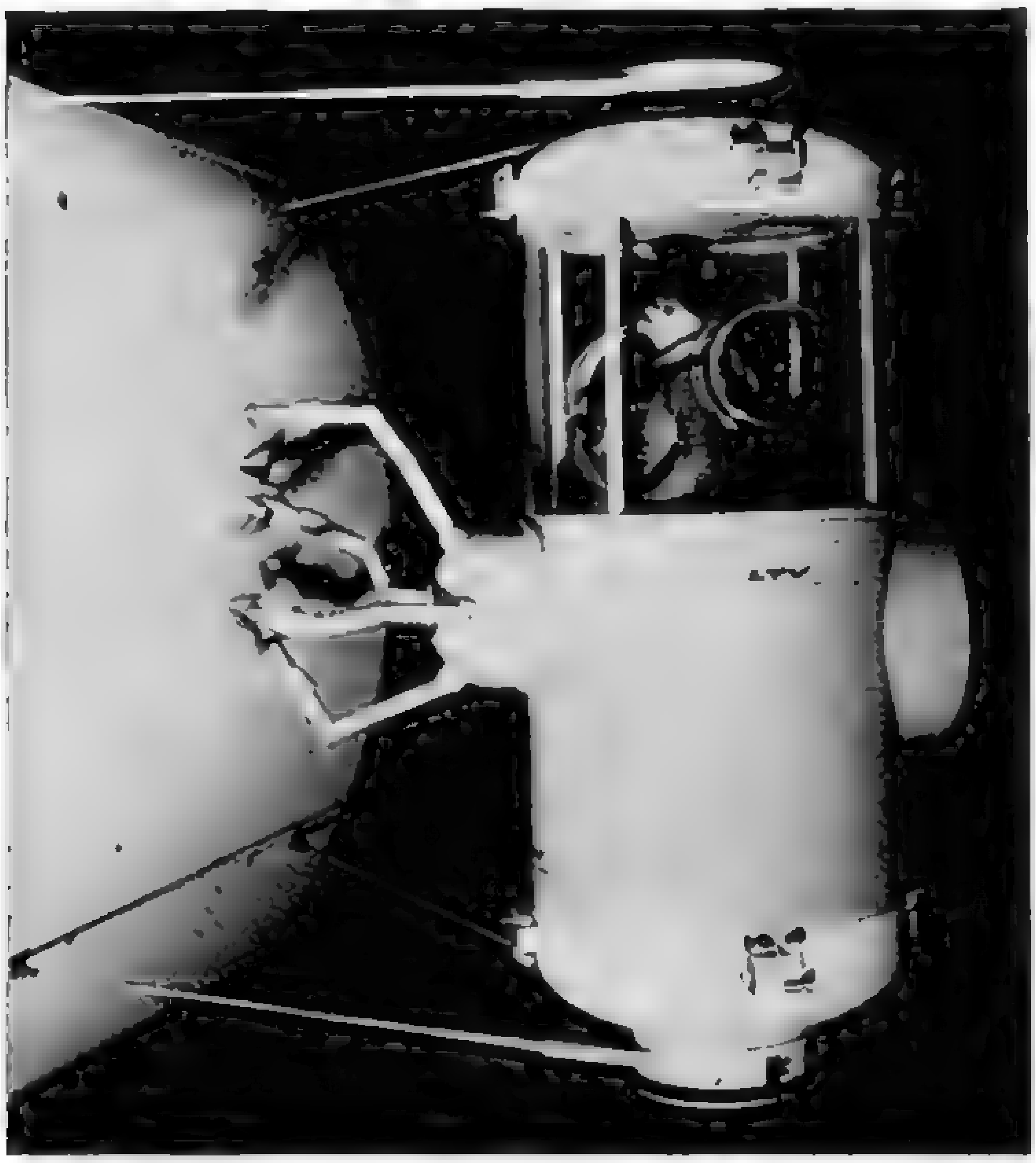


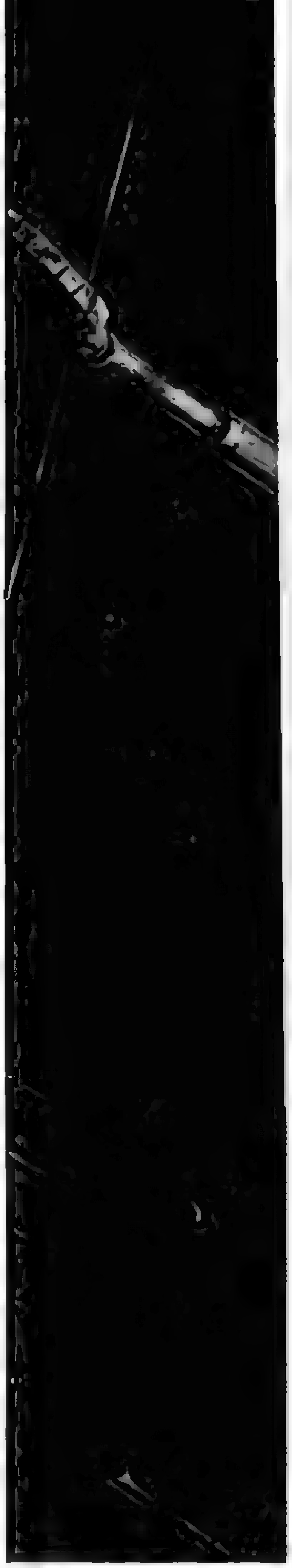
A 'Mr. Fix-It' Space Car

When multimillion-dollar satellites conk out, a repair-making spacecraft with deft mechanical arms could put them back in working order—and here's a preview of what it may be like

By DR. WERNHER VON BRAUN

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.





Space-repair car may look like one-man version at right. With manual controls, operator wields "hands" to grasp satellite and handle detached parts, and drill and other tools.

One-man "space taxi" is another concept of a repair craft. Model shows it anchored to satellite and going to work with remote-controlled "hands."

Insect-like spacecraft with multiple fangs—manipulators and tools extending from their roundish bodies—may become the "Here-Comes-Help" wrecker cars of the Space Age.

Some of NASA's highly complex unmanned research satellites such as OAO-2, the Orbital Astronomical Observatory, have been eminently successful. A few, such as its predecessor, OAO-1, became bitter disappointments when a single component's failure turned a sophisticated multimillion-dollar array of instruments into useless orbiting junk.

Our astronauts' often-demonstrated ability to remedy troubles with ailing equipment has led to studies of how they could bring disabled satellites back to life. While the problem is not simple, there are promising possibilities.

A garage mechanic's ability to fix your car depends upon the attention the car's designer has paid to making critical parts accessible and easy to change and suitable tools available. As our unmanned satellites were never meant to be fixed

n orbit, no attention at all was paid to hese things in their design. But this :ould be done in the future, now that we :now we could send a repairman.

Being able to rendezvous an out-of-ırder satellite and approach it by "space-valking" is not enough. The sick satel-ite may be tumbling and its whirling, ›rotruding parts may imperil an ap-›roaching EVA (extravehicular-activity) nan. Concepts to stop the tumbling mo-ion include a magnetic grappling device ›rought into position by a fearless space valker. This done, repair can begin.

But, prior to the therapy, there must ›e a correct diagnosis of the trouble—ınd only rarely will our repairman know ıis patient's ailment in advance.

Finding the trouble. Advanced space-craft, manned or unmanned, are usually checked out (and monitored during countdown) through an external multi-pronged electric connector—which is dis-engaged at takeoff or shortly before. For his diagnosis, a space repairman must bring along a tape-controlled electrical-checkout device, plug it into that same spacecraft connector, and run a fault-isolation test.

Suppose he finds a certain valve of the satellite's attitude-control system must be replaced. The valve is part of a high-pressure system; removing it calls for disconnecting an electrical control cable and opening two B-nuts. For an EVA

Continued

To check the tumbling of a disabled satellite, which would endanger an approaching repairman, a space-walker may use a long-handled "magnetic grappling device" as pictured. Once the rotation of the satellite has been stopped, the repair task can begin in earnest.

man in pressurized suit and gloves, this would be a major task, even if he had brought the right-size wrench.

The answer seems to be the manipulator, a device highly perfected for the atomic energy program. A manipulator is a mechanical or electromechanical "repeater" of the movements of your arms, hands, and fingers. You stick your fingers in the "command" end of two manipulator arms. Through mechanical or electrical linkages or both, mechanical hands on arms at the "business end" repeat your motions.

These manipulators are nimble enough to cut a deck of cards, and pick a card out of the middle of the deck. During a visit to the famous Oak Ridge laboratories, I was taught the trick of taking a match out of a matchbox, closing the box, picking up the match again, and rubbing it along the box to strike a light—all with two manipulator arms whose business ends were six feet from me, beyond thick radiation-proof glass.

The space-repair craft. For space use, an operator would wield these manipulators from a craft that could be maneuvered and attached to a disabled satellite. What it may look like is shown by pictures on the preceding pages. As they indicate, it may have more than just two arms. Some arms may not be repeaters of finger movements, but tools like drills, tongs, or hammers, instead. Others may anchor the car in front of its work.

To perform precision tasks with a manipulator, you must have the "feel" of doing the job with your own hands. So a critical need, as I learned to appreciate when I tried to strike that match, is "force-feedback." This means re-creating the forces experienced by the business end, at the command end.

Purely mechanical cable-driven manipulators give reasonably good force-feedback, but raise sealing problems for a manned spacecraft—with the operator in a pressurized cabin, and a hard vacuum outside. Electromechanical systems pose a formidable force-feedback problem involving strain gauges, bridge circuits, and the like. Acceptable designs exist but are complex and susceptible to failure. Undoubtedly, improved designs can be expected in the near future.

A space-repair car, it may be foreseen, would be dispatched to a task from an orbiting "mother" spacecraft or space station, and would return and dock to this operating base when the job was done. The repairman would be able to transfer, in orbit, from the mother craft to the docked repair car and back, without ever leaving his pressurized environment. (He would get from earth to orbit, and ultimately back to earth again, by way of the base's own logistics supply-ferry system.)

How about unmanned repair cars? A remote-controlled "robot" repair vehicle—with the man replaced by an operator on

[*Continued on page 212*]

Space-suited experimenter, using remote-controlled mechanical hands, tries manipulating objects on NASA test panel at Argonne National Laboratory.

Coming—A "Mr. Fix-It" Space Car

[*Continued from page 100*]

the earth—has been an alternate sugges tion. However, this offers problems:

An operator on earth must view th repair operation on a TV screen. If th satellite is in low earth orbit, he will hav it in direct line of sight (above his hori zon) for no more than seven minutes- too little time for a sizable job.

So the TV picture may have to be re layed to earth via a communications sat ellite in 22,300-mile-high synchronous or bit. It would then have to travel so fa that it would reach the screen only afte an appreciable delay. The "force-feed back" over a radio link would also be sub ject to this delay; in addition, of course the finger movements at the "comman side" on earth would suffer the same radio propagation delay before they were re peated at the "business side" in orbit While this awkward wait for a groun operator to see and "feel" what he is doing may not rule out the whole idea, it does present a handicap to be considered.

Looking ahead. Future manned spac stations probably will have numerous modules for various scientific and opera tional activities—some rigidly intercon nected, others floating freely near the central cluster. Repair spacecraft manned or remote-controlled from the station, may prove vital to keep the com plex operative for long periods.

Such large space structures as vas radio-astronomy antenna arrays or Palo mar-size telescopes, even if they operate and report data by remote control, un doubtedly will need occasional manned servicing. It will be impossible to plan their scientific tasks for years ahead—and space cars that can exchange their instru ments will permit updating them, vastly extending their flexibility, scientific value and useful life.

Finally, the handy-man cars may be come a necessity to future manned inter planetary expeditions. These will require nuclear-powered rocket ships, carried piecemeal into an earth-circling depar ture orbit by powerful chemical rockets like Saturn V. Assembling and checking out the spaceships in earth orbit could be greatly facilitated by manned cars like the one pictured on page 99. ■

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By Dr. William Haddon

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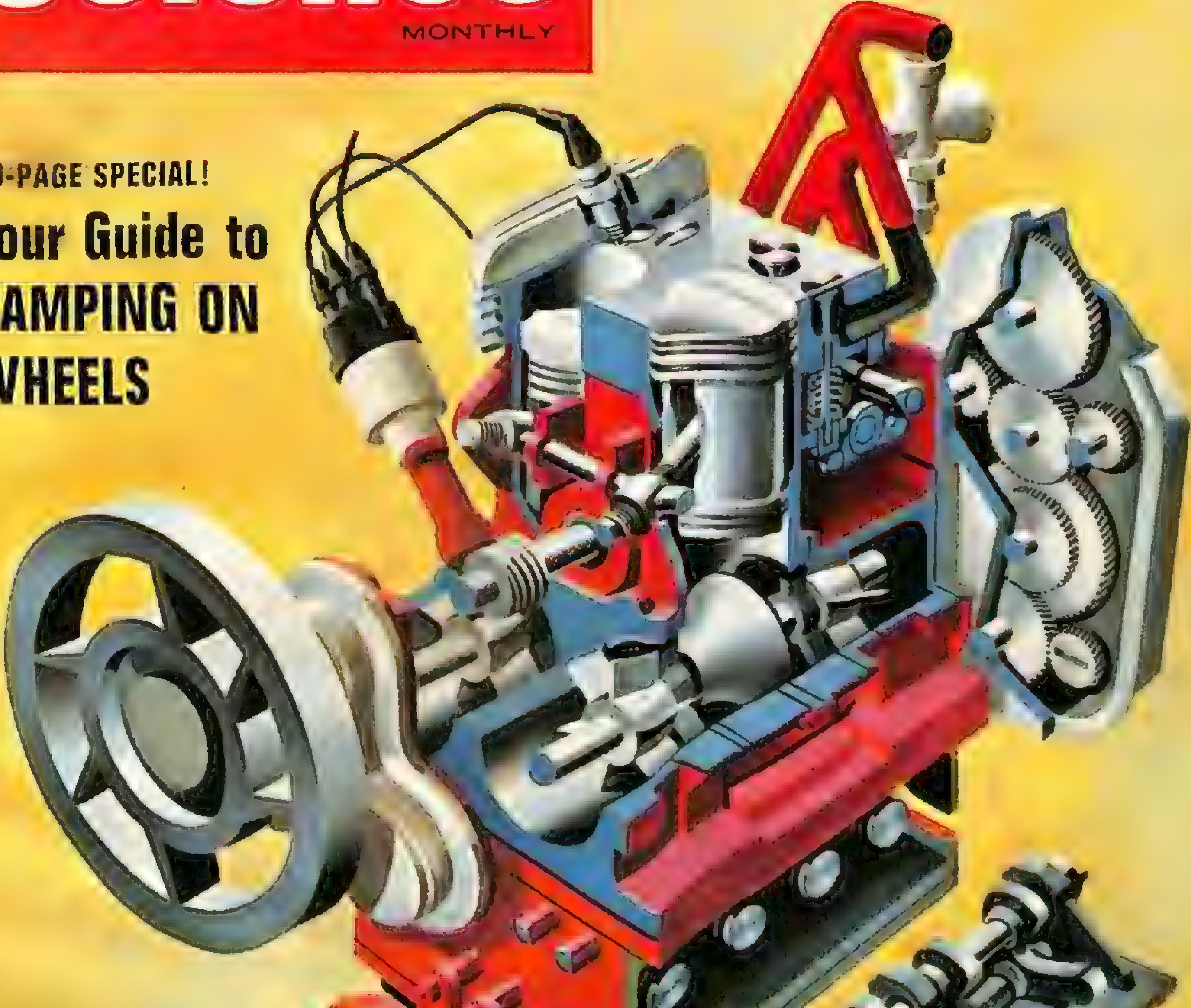

Astonishing New French E

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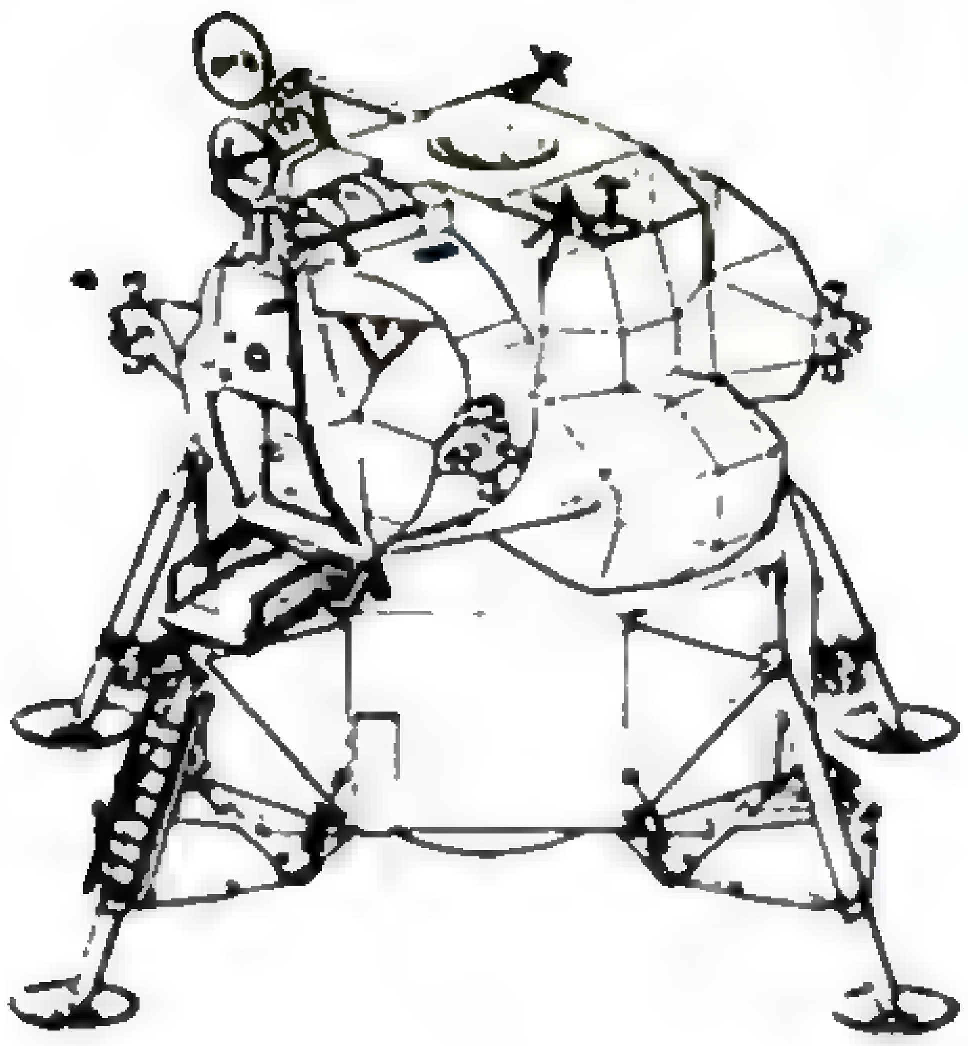
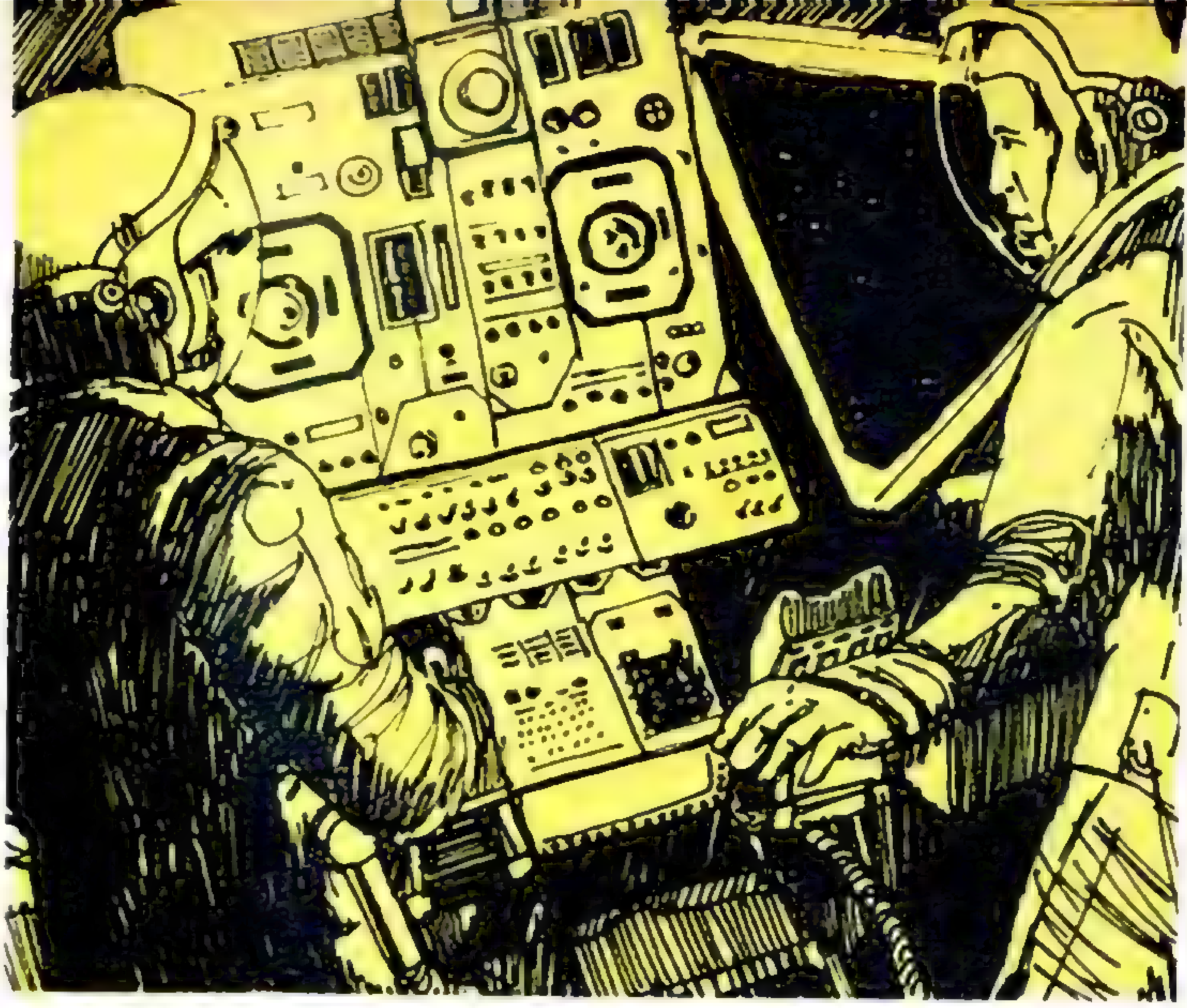




Inside our newest manned spacecraft—

The Moon-Landing "Spider"

By DR. WERNHER VON BRAUN

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

The man who has a key role in rocketing the Lunar Module to the moon tells the story behind the novel two-man vehicle, due next to be flown in lunar orbit

Successfully flown in earth orbit by Apollo 9 astronauts last March, our newest manned spacecraft—the two-man Lunar Module, known also as the "Bug" and more recently as "Spider"—will go to the moon next.

In the Apollo 10 flight this month—our second manned lunar voyage, proceeding this time almost to a landing—two astronauts will skim to within 10 miles of the moon's surface in the Lunar Module. That will be its final trial before the Apollo 11 moon landing planned with it for this summer. The Lunar Module completes the array of two spacecraft and their Saturn V launch vehicle needed for that great adventure.

To voyage through space, the Lunar Module is linked to its mother spacecraft—Apollo's three-man Command and Service Module. But the Lunar Module can be separated and flown under its own power, as will be done to descend

Continued


Coming next: Lunar Module makes a descent toward moon's surface

In lunar orbit, two astronauts in Lunar Module cast off from mother ship, the Command and Service Module, in which third astronaut remains. Maneuvering away with small thrusters (left), Lunar Module then fires its descent engine (right), braking itself in orbit and starting its descent. In Apollo 10 landing-rehearsal plan, it skims surface and returns; in Apollo 11, it lands, as pictured on opposite page.

Designed for space only, Lunar Module had its beginning

toward the moon's surface and come back.

Thus, for the first time, Mission Control at Houston has to keep in touch with two manned spacecraft at once—incidentally adding, to their nicknames, their respective radio calls. In the Apollo 9 mission these were "Spider" for the buglike Lunar Module, and "Gumdrop" for the Command and Service Module (because these modules in their blue-plastic wrap for shipment resembled wrapped gumpdrops, the astronauts thought.

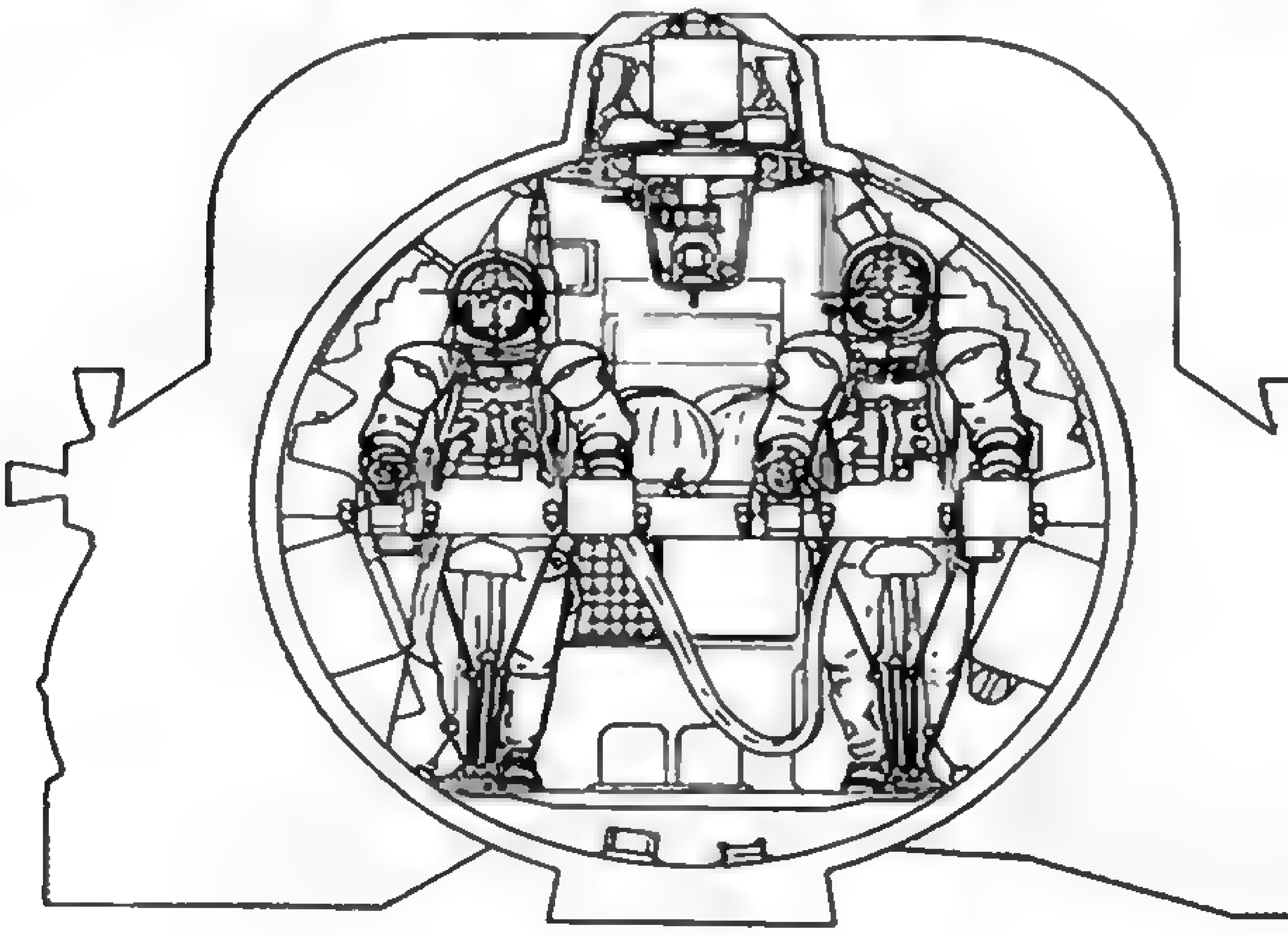
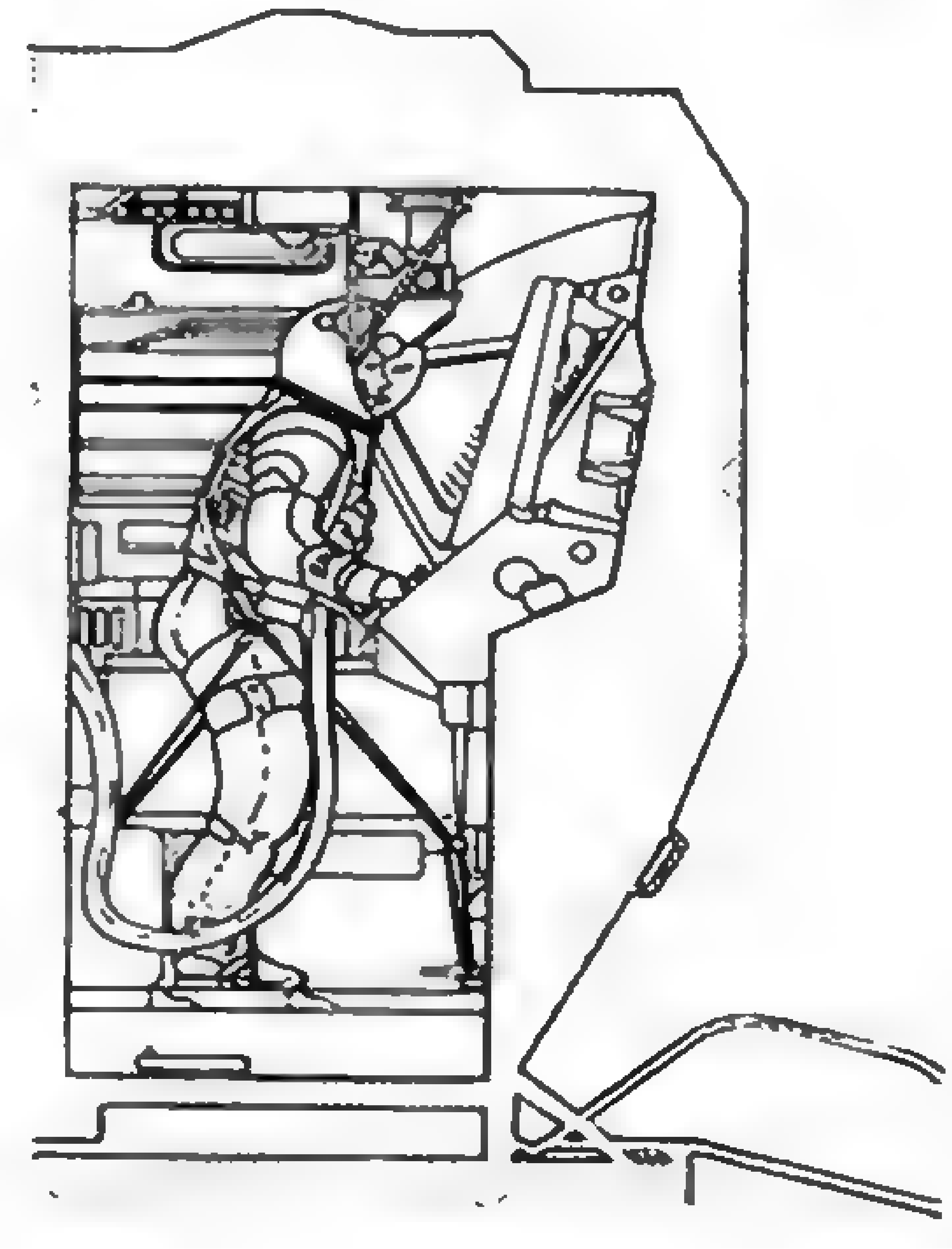
First manned vehicle for space only, the Lunar Module needs no streamlining—it flies in a vacuum. Lacking a heat shield, it cannot return to earth. The lives of its crew depend on a rendezvous with its reentry-capable mother craft—a feat that was accomplished from more than 100-mile distance in the Apollo 9 mission.

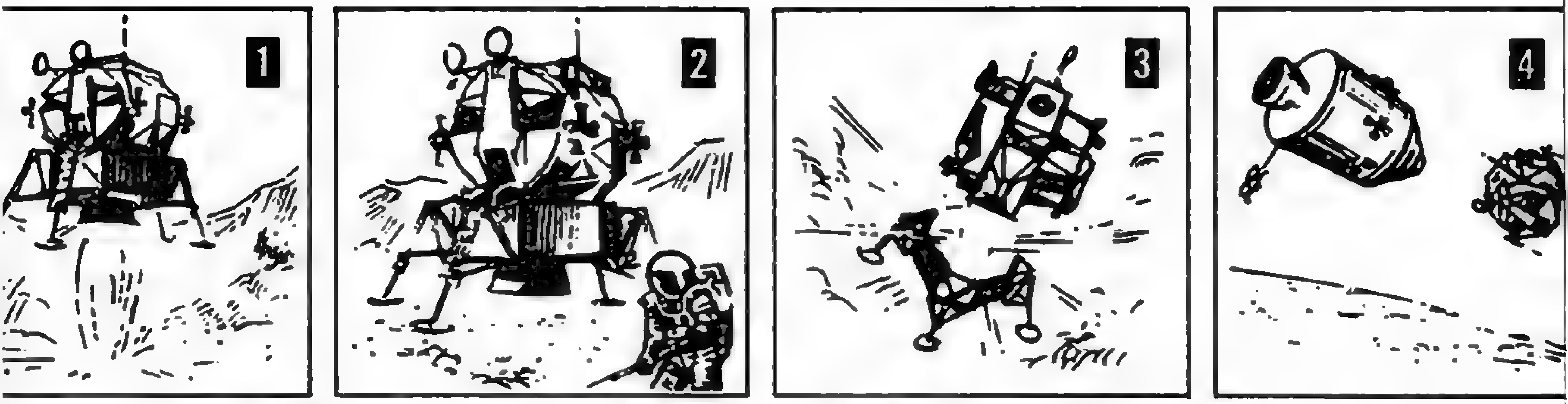
The "why" of the Lunar Module. Behind the new craft lies the interesting story of how it came into being.

When NASA accepted President Kennedy's challenge "to land an American on the moon in this decade," it was not even clear that a Lunar Module was needed at all. The decision to include it in the program was made a whole year later, when NASA selected the Lunar-Orbit Rendezvous plan as the way to go.

Two other methods were considered. One was a "direct" flight from the earth's surface to the moon and back. The other, the Earth-Orbit Rendezvous plan, envisioned assembly of a moon vehicle in earth orbit, from two elements brought up by two Saturn V rockets.

Two-man crew of Lunar Module ride standing up (left) in cylindrical cabin. Straps hooked to their suits at waist (right) exert 30-pound downward force through pulley and reel system and, together with armrests and boot-engaging Velcro in floor, help brace them in low or zero gravity. They enter and leave cabin by a docking hatch overhead—or, on moon, a forward hatch to a ladder.



Climax of Apollo space flights will be Apollo 11 landing of two astronauts on moon in Lunar Module. Thumbnail sketches by Grumman artist show sequence of events: 1) Hovering Lunar Module, supported by blast of its descent engine, settles slowly to a touchdown on moon. 2) Astronauts emerge and explore moon's surface. 3) Returning to Lunar Module, they fire its ascent engine and take off in its ascent stage, using the descent stage as a launch pad. 4) Lunar Module makes rendezvous with mother spacecraft, the Command and Service Module, in which all three astronauts return to earth.

n choice of Lunar-Orbit Rendezvous way to moon landing

How wise does our 1962 choice of the Lunar-Orbit Rendezvous look from the vantage point of our hindsight today?

A direct flight would have called for a launch vehicle with 12 million pounds of takeoff thrust—substantially more powerful than Saturn V, with eight F-1 rocket engines in the first stage where the Saturn V has five. This huge launch vehicle probably could have been developed by now. However, its cost would have been substantially higher than Saturn V—and its usefulness for anything but manned lunar missions would be questionable for years to come.

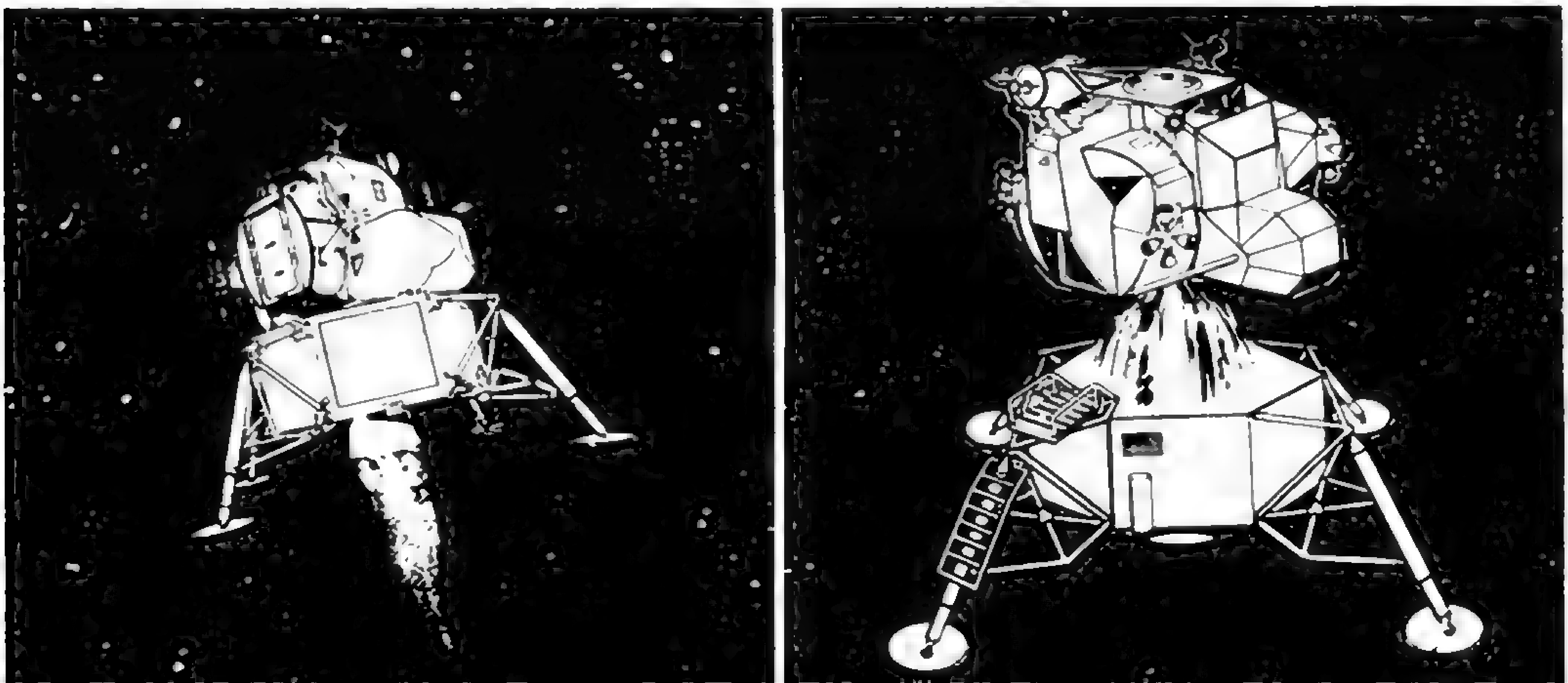
The Earth-Orbit Rendezvous plan would have carried the Command Module all the way to the lunar surface, obviating the need for the costly development of a separate Lunar Module. In concept it, too, would have proven sound. Its key requirements, a Saturn V launch vehicle and the capability of rendezvous in orbit, are the same as for the Lunar-Orbit Rendezvous choice.

But if I had to make a selection today, with all the advantages of a Monday morning quarterback, I would cast my vote again for the Lunar-Orbit Rendezvous. Here are my reasons:

The Command Module, serving as the main flight deck on the way to the moon and back, must make a blazing reentry at an initial speed of 25,000 m.p.h.—with decelerations of four *g*'s and possibly more. But heat shields are not too compatible with high-visibility windows. And excellent visibility from the cockpit

Continued

A two-stage self-propelled spacecraft, the Lunar Module stands 23 feet high overall. Lower part, with moon-landing legs, is descent stage; upper part, where crew ride at all times, is ascent stage. Each has own rocket engine. Come-apart craft descends to moon in one piece, using descent engine (left). To reascend, ascent stage separates and fires ascent engine (right), leaving descent stage on the moon.



Lives of Lunar Module's crew depend on making a successfu

comes first and foremost for a landing on the moon, with such requirements as avoiding local obstacles. Problems of aerodynamic shape, air-friction heating, and high g's are nonexistent there.

I am not saying that a Command Module capable of earth reentry and a pinpoint lunar landing too is beyond future possibility. But now in 1969 I am convinced, maybe even more than I was in 1962, that it would have been asking for trouble to select a plan coupling problems of reentry and lunar landing—two areas where existing experience was nil.

Not too surprisingly, it took a while before realistic requirements for a vehicle enabling one or two astronauts to descend from a moon-orbiting mother spacecraft to the lunar surface, and return, were fully understood. The first proposals for such vehicles were clearly inadequate. One early concept, for instance, was a one-man Lunar Module that weighed only 1,800 pounds, relied on the astronaut's spacesuit for life support, and depended on "a plumb bob, stopwatch, and reticle," as one skeptic remarked, for navigation and flight-path control.

In contrast, the original configuration proposed by the successful bidder in the Lunar Module contest, the Grumman Aircraft Engineering Corp. of Bethpage, N.Y., was to weigh about 24,000 pounds when fully loaded with propellants.

It grew and grew. By the time NASA felt all its requirements were met, the contracted weight was 28,500 pounds. And it kept on rising as details of a vehicle able to land on the moon, and support two astronauts' activities for a day there, came into better focus.

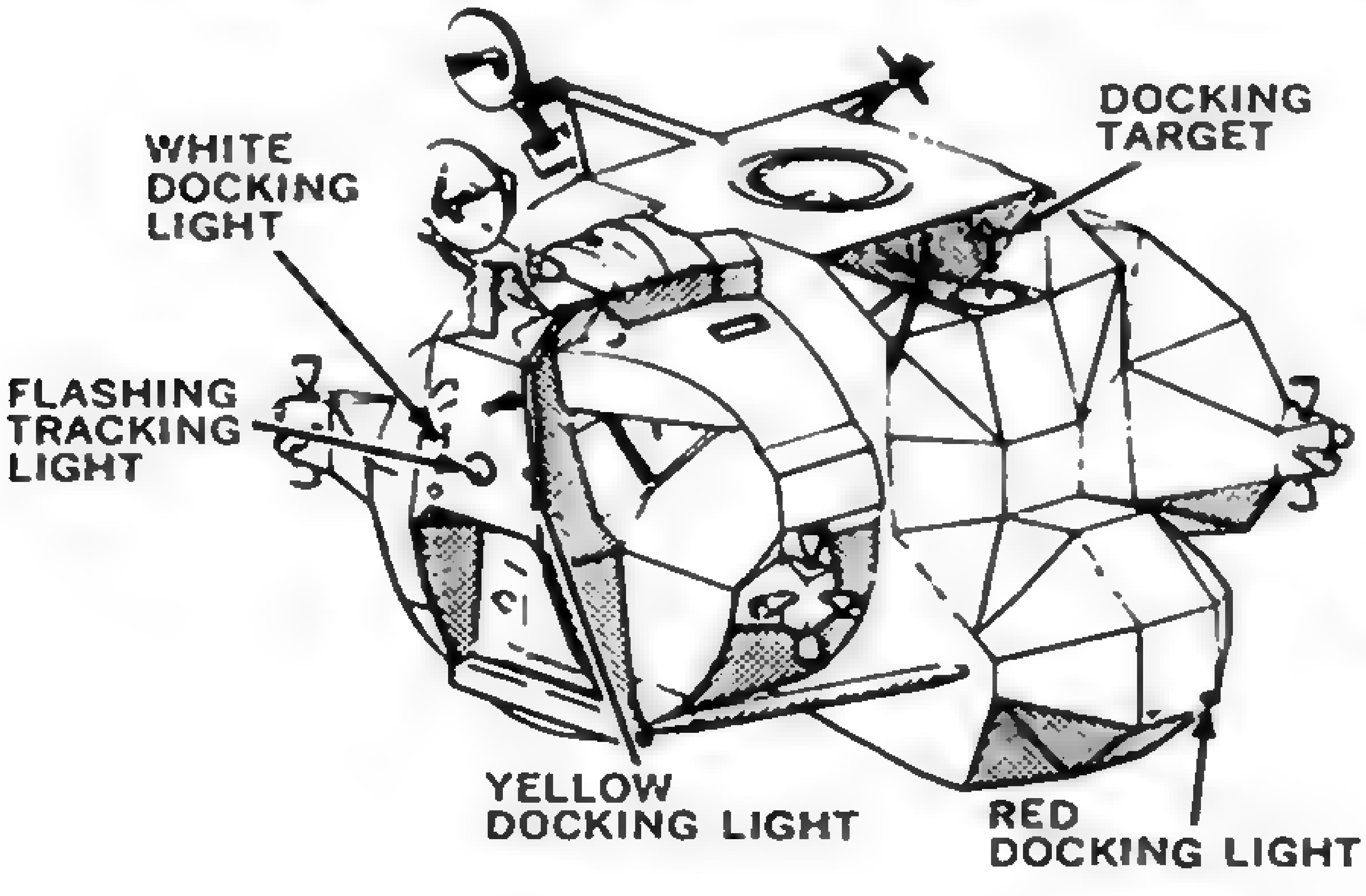
As time went by, we at Marshall Space Flight Center were asked whether we couldn't raise the promised 90,000-pound lunar-payload capability of the Saturn V to 95,000, 98,000, or even 100,000 pounds, mainly to accommodate those ever-growing weights of the Lunar Module. Well, for Apollo 11—the first lunar-landing attempt—we are now committed to a lunar-injection payload weight of 102,000 pounds.

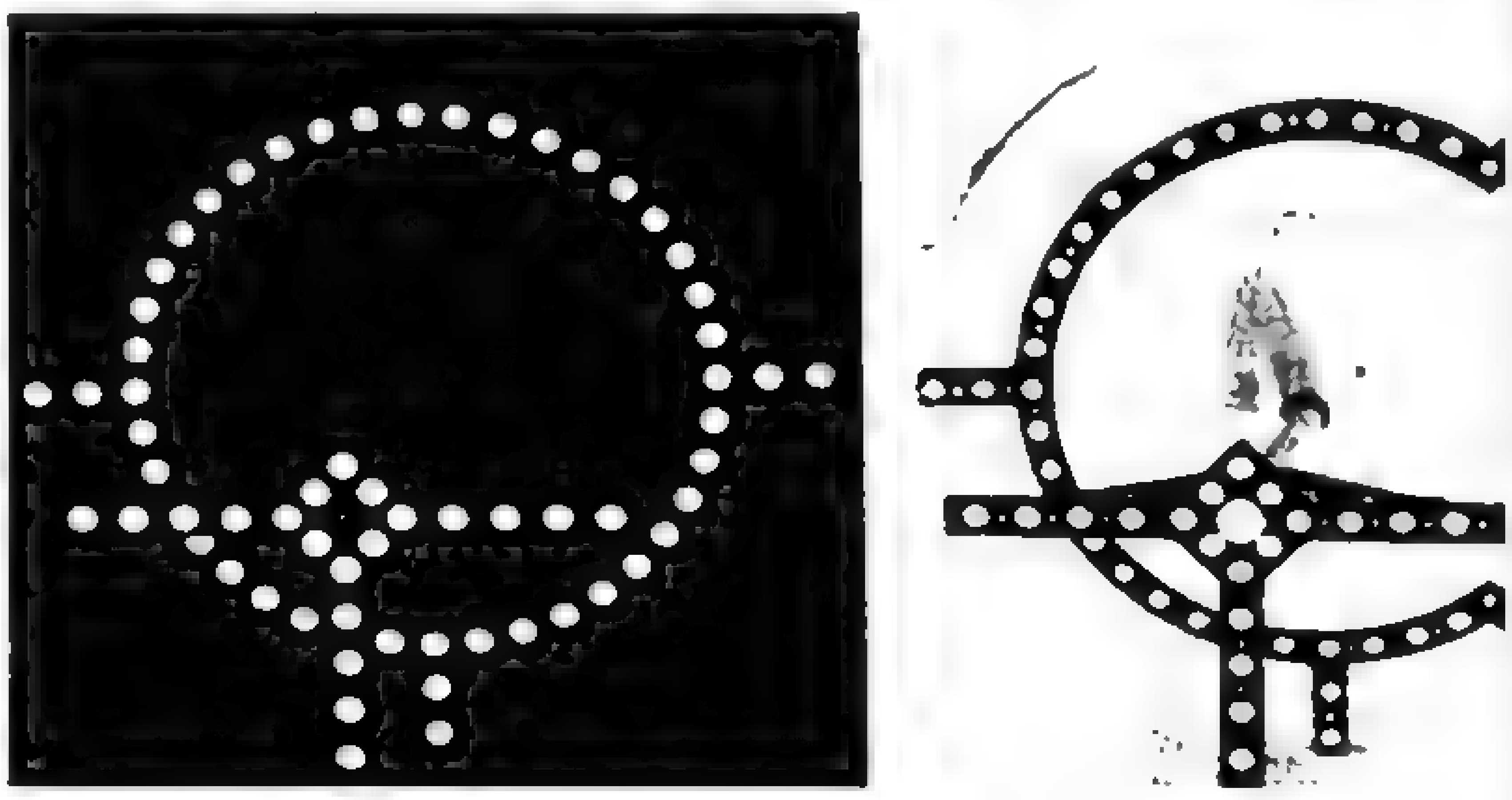
We know that the fully loaded Lunar Module will weigh 32,500 pounds, and that a major and costly effort by both Grumman and NASA was required to stick even to that weight ceiling. Latest advances in microcircuitry had to be incorporated in the Lunar Module to keep the weight down. Structural integrity of the entire craft was reevaluated, and metal was shaved or chem-milled off wherever a pound could be saved.

The Apollo fire of 1967 added to the Lunar Module's teething troubles. When it was determined that any idea of abandoning the pure-oxygen concept for the Lunar Module and Command Module was unrealistic, a witch-hunt began for anything combustible, particularly in the Lunar Module's crew compartment.

Clinging hook-and-pile Velcro tape, the Gemini astronauts' favorite for zero-gravity support, all of a sudden was in the doghouse as a major potential fire hazard. Its makers responded with a fireproof version of Velcro. Food-storage

Lit up for rendezvous, Lunar Module looks from afar like a firefly. Once a second it flashes high-intensity tracking light, visible 150 miles to naked eye and 460 miles through sextant's telescope. Docking lights have 1,000-foot range. Target for docking, made by 3M Company and shown in dark and sun, has self-luminous buttons whose green glow (induced by radioisotope) can be seen 200 feet away.





ɔreas were covered with fireproof Beta cloth. The electrical system was fireproofed. The drinking-water supply was tapped for a hand-held water gun to quench any little fire.

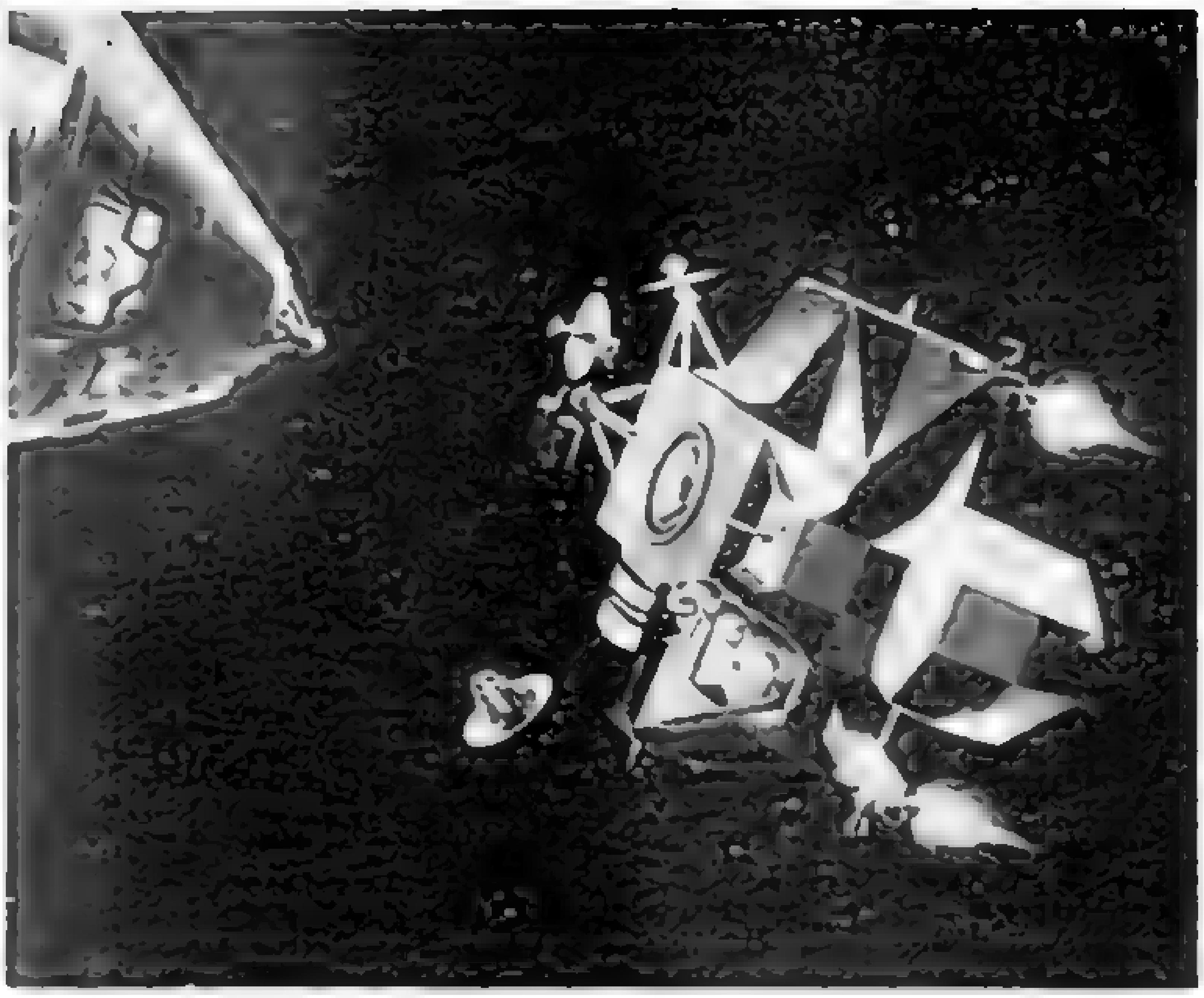
The rocket engines raised problems. The 9,870-pound-thrust descent engine was to be throttleable from 10 to 100 percent of full power, but ran rough between 65 and 95 percent; NASA ultimately decided the landing-guidance system could handle that problem, and waived the requirement for stability in the 65-to-95-percent throttling range. The 3,500-pound-thrust ascent engine's severe combustion instability and excessive erosion of its ablative thrust chamber led to a new injector, from a new contractor.

Alloys' ailment. A crisis arose with stress corrosion—the plague of some of our highest-performing aluminum alloys. A material perfectly corrosionproof when not under load develops corrosion cracks after a time under stress. Spurred by NASA, Grumman surveyed the Lunar Module and identified 45 parts, critical to mission success, as potentially susceptible to stress corrosion. A lot of Lunar Module hardware was then already on the assembly line. But, for Lunar Module flights before the lunar-landing attempt and not weight-critical, a few heavy and easy fixes would suffice.

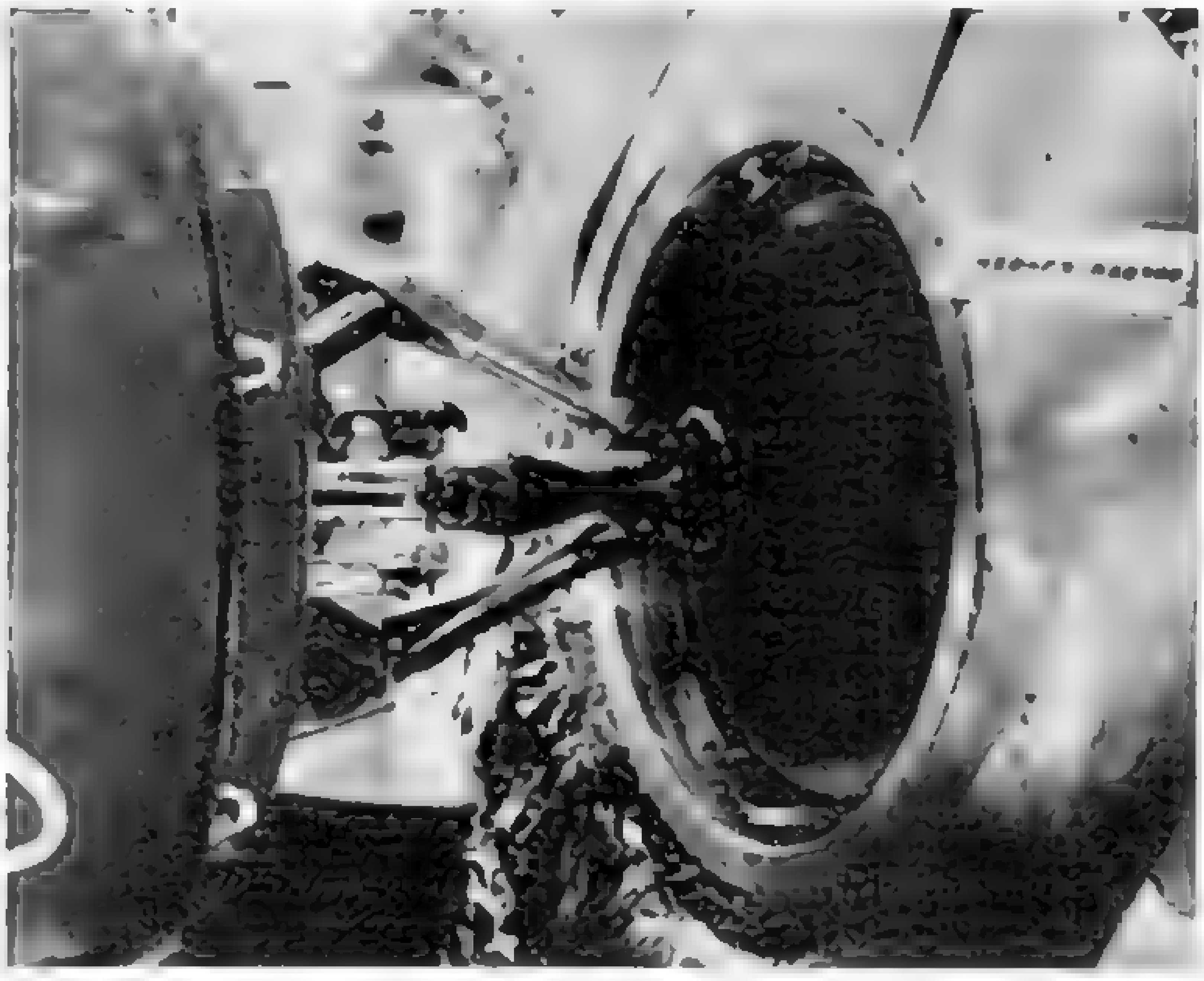
The decision was made to incorporate all ultimate lightweight remedies in the Lunar Module effective with Apollo 11. This is one of the reasons why the Apollo 11 Lunar Module will be the first one capable of a lunar landing.

The Lunar Module's most recent problem was actually an old acquaintance in the aerospace business. We call it "electromagnetic interference." You observe it if your TV set gets fuzzy every time the dishwasher cycles. All you can do is call an expert to fix it, and that is what NASA did—but the fix-it man needed time. So the Lunar Module's first manned flight, intended to precede the unforgettable Apollo 8 mission around the moon last Christmas, had to await this March.

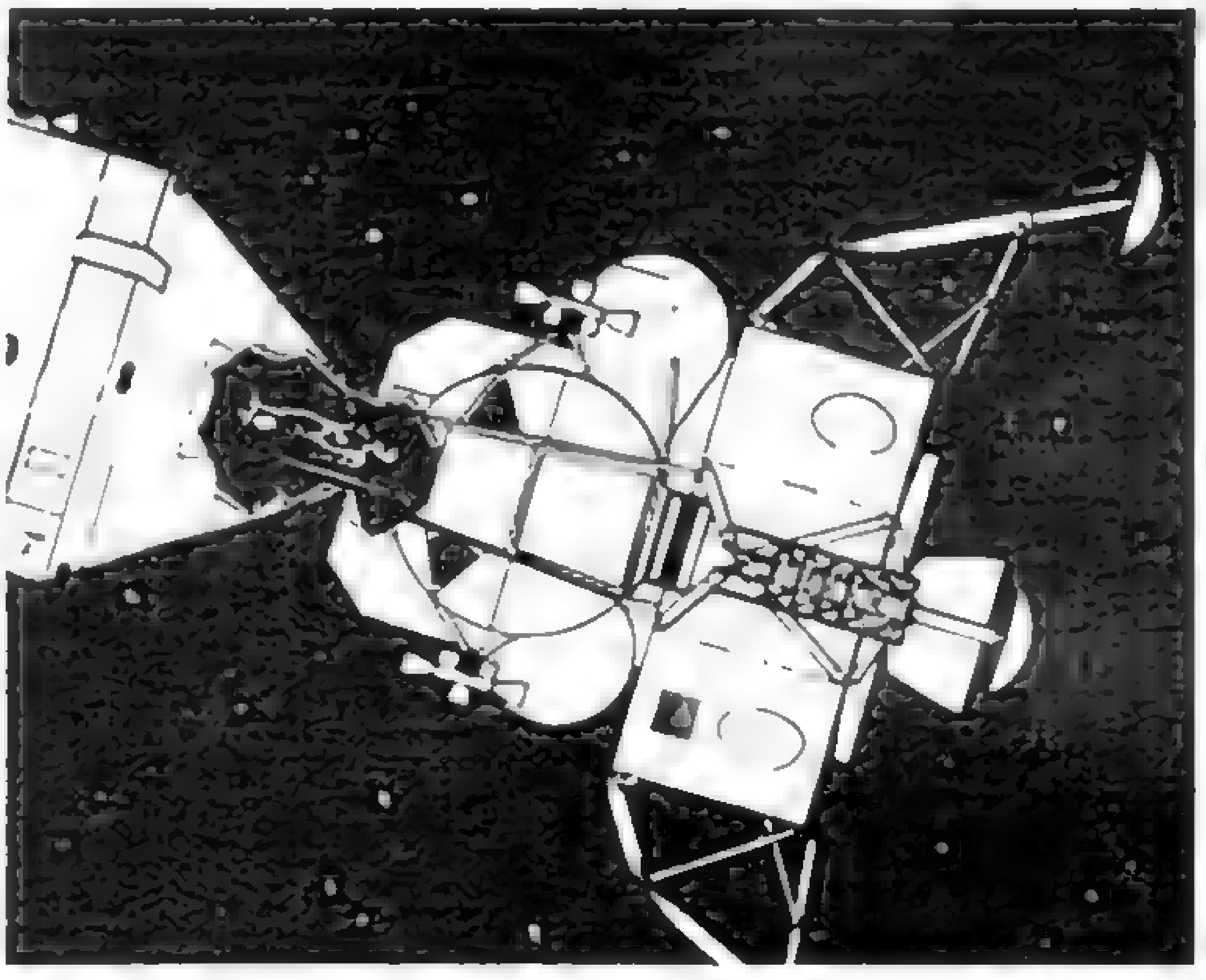
That flight, Apollo 9, was the Apollo program's last earth-orbiting mission. Henceforth the Lunar Module and its mother craft will be moonbound.



Maneuvering with thrusters, Lunar Module approaches mother craft to dock. It makes linkup by engaging a cone-shaped member called a drogue with a probe at nose of Command Module.



Tip of probe, entering conical drogue as seen in this photo of docking mechanism, latches to aperture at drogue's center. Probe retracts, drawing two craft together—and a ring of latches secures them.



To reenter mother ship, Lunar Module's crew use this tunnel connecting docked craft, after clearing it of removable docking hardware. If mishap barred the way, they could space-walk from hatch to hatch.

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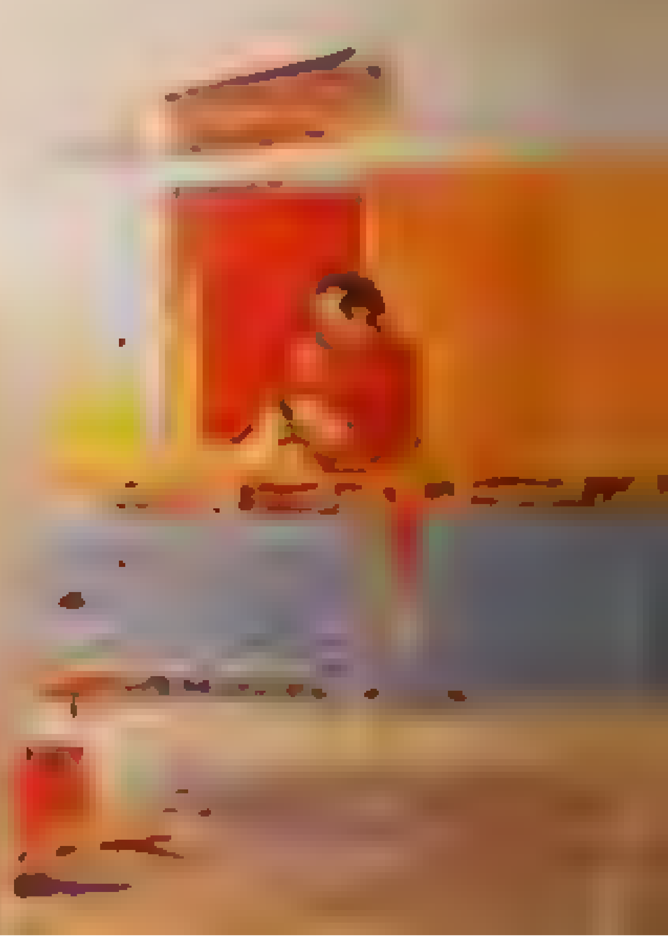



Here is your guide to
Apollo 11,
our most fantastic
space adventure.

By DR. WERNHER VON BRAUN

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

to try to put the FIRST MEN ON THE MOON

A famed rocket scientist takes you across a quarter-million miles of space to watch this month's climactic lunar-landing attempt by our astronauts

In the two-man cabin of the Apollo 11 Lunar Module, slowly riding down its vertical rocket jet, blue signal lights flash on. Probes dangling 60 inches below the disk-shaped footpads have touched the moon. The pilot cuts the engine. A moment later, a mild jar tells the crew they have landed on the moon's surface.

That is to happen early in the afternoon of Sunday, July 20, 1969, in the western part of the moon's Sea of Tranquility, according to NASA's plans at this writing. Chosen to attempt the first manned lunar touchdown are Apollo 11 Commander Neil Armstrong and Lunar Module Pilot Edwin ("Buzz") Aldrin. Circling above the landing site in their moon-orbiting mother spaceship, the Command and Service Module, will be Command Module Pilot Michael Collins.

Success in Apollo 11's great adventure would realize our aim of putting men on the moon within this decade. Millions of Americans will share the suspense and thrills of the fantastic mission as they watch it unfold on their TV screens. Here is an advance look at what the Apollo 11 astronauts mean to do, and a guide to key events on which success will hang:

The dash to the summit. Man's first touchdown on the moon can be compared to the final spurt to a lofty mountain's summit by a few select climbers, starting from the highest of a string of base camps set up by others of their expedition.

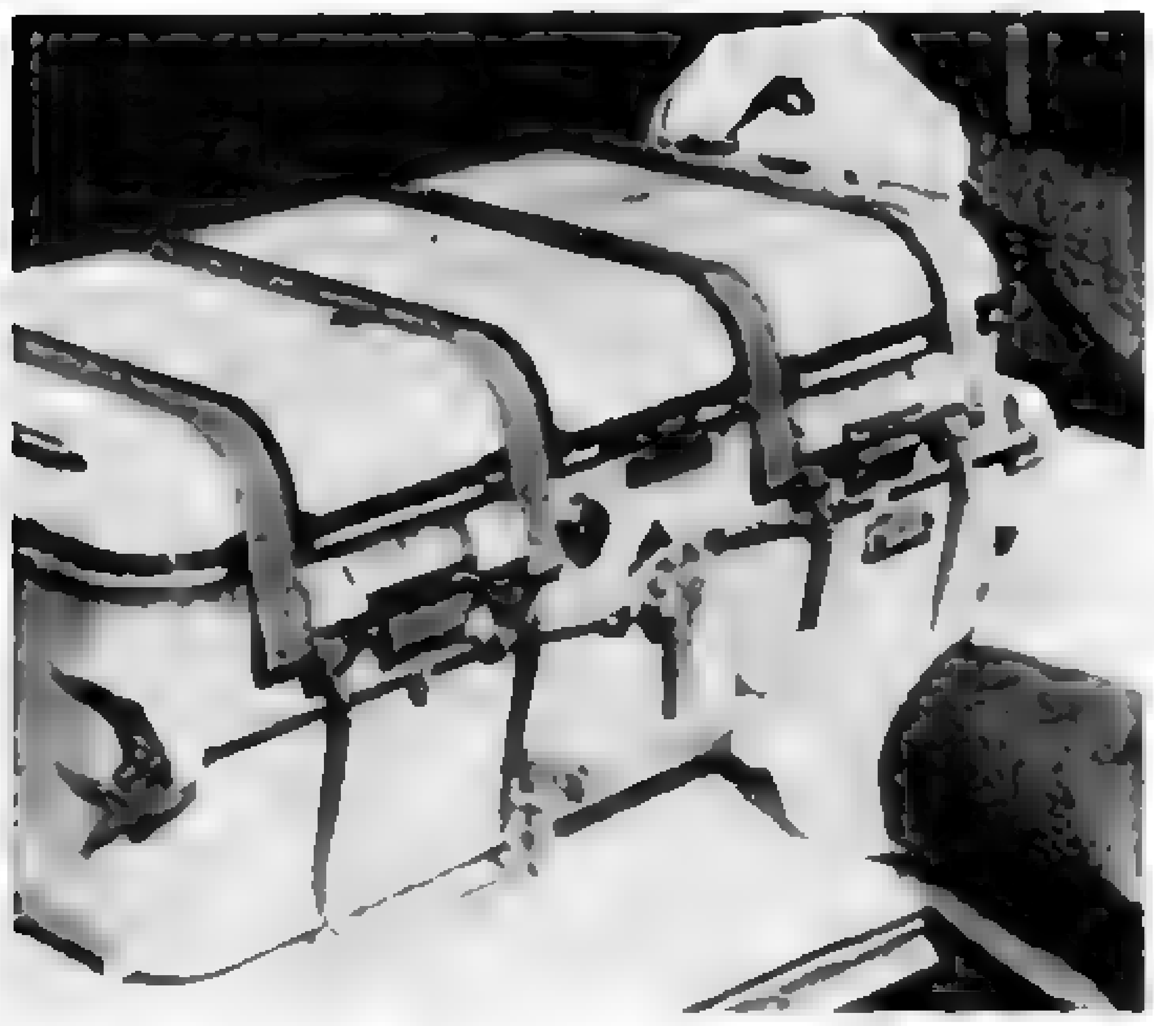
Apollo 7 proved out the Command and Service Module (CSM). Apollo 8's moon voyage took men in and out of lunar orbit. Separating and docking the Lunar Module (LM) was rehearsed in earth orbit by Apollo 9, and over the moon by Apollo 10. Now all is ready for the assault on the summit—the moon landing itself.

Apollo 11, up to a point, will retrace the moon-voyaging route of Apollo 8 and 10: the Saturn V launch into earth orbit, scheduled for July 16; re-ignition of the Saturn V's top stage, to propel the craft

Continued

Apollo 11 astronauts explore lunar surface within radius of 50 to 100 feet from landed spacecraft. Composite view of activities pictures them televising eerie moon scene, collecting lunar rocks, setting up experiments to leave behind.

ILLUSTRATION BY BOB McCALL



Treasure chests from moon will be two rock boxes like one above, crammed with lunar samples. Astronauts, who cannot bend over in backpack-laden garb, pick up moon rocks with long-handled scoops as in NASA trial pictured at right.

begins tilting toward vertical and using its descent engine to check its fall.

As it turns upright, the moon's surface, out of sight of the crew before, creeps into view from the bottoms of their windows. What they see is a flat and comparatively crater-free lunar plain—almost on the moon's equator, at 23 degrees east, lunar longitude.

Look at the moon from earth and this landing site will be a little short of midway from the moon's center to its right-hand edge. At the time of the landing, when the moon will be nearing "first quarter," it is barely within the sunlit zone. Purposely the touchdown is timed for early in the lunar morning, so that long shadows will vividly show up the relief of the terrain.

Selecting a landing spot free of obstacles, the crew tilts the whole craft until this target is at the zero point of a windowpane scale, whose fluorescent markings glow green and orange in the dark. Then they trigger a "mark" button to pin it down. This sets their inertial-guidance system to lead their descent path to it automatically.

At a point less than 1,000 feet up, called the Low Gate, the Final Approach Phase ends and the Landing Phase begins. The crew can choose an "auto" mode that does it all automatically; a semiautomatic mode, in which the LM Pilot controls the rate of descent; or a completely manual mode for a helicopter-style landing by eye. A likely choice is the semiautomatic mode.

The hovering Lunar Module descends toward a touchdown at three feet a second. Any remaining horizontal velocity will be even less. Keeping it to a minimum, and avoiding sloping ground and obstacles, are important to avert a disastrous tip-over. The LM is pretty forgiving about a less-than-perfect landing—but, even so, it will be a tense moment when the spidery legs' footpads settle into lunar soil.

After the dramatic news that the crew are safely down on the moon, a little time elapses before further events, for the astronauts do not emerge at once. It takes them awhile to check their craft, and then struggle into "moon suits" with life-support backpacks, even if they should forego a rest period before their strenuous activities outside.

Footsteps on the moon! Finally comes the high spot of the mission—an action-packed program of two hours and 40 minutes of "moonwalking."

Descending a ladder from the forward hatch, Commander Armstrong is to be

Continued

first to set foot on the moon. Almost his first act is to scoop up a bagful of loose lunar soil, and hand it up to Aldrin to stow away. That "grabbag" sample guards against returning empty-handed, if anything should compel a premature takeoff. (You may be sure planners are thinking of nothing so fanciful as a hostile reception by little green men—but of such imaginable contingencies as a leak in the ascent propulsion system, or trouble with life-support equipment.) Then, after Armstrong has tested walking on the moon, and inspected the craft's exterior to make sure it has suffered no damage in landing, Aldrin joins him outside.

Earth viewers will share by TV the eerie lunar scene confronting them—a stark gray desert, airless and lifeless, unrelieved by colors, harshly painted by the sun with glaring highlights and inky shadows. High in the black sky hangs the remote earth. The only nearer human being is Collins in the CSM, which they see sail overhead every two hours. Their mother ship looks to them like a star, except that it is moving rapidly across the heavens, as it orbits the moon.

Dark gold-coated visors of the moon-explorers' red helmets shield their eyes from the sun's glare. They wear heavily insulated "lunar overshoes"; underfoot, the moon's soil is still frigid after the extreme cold of the 14-day-long lunar night, although it will become hotter than boiling water during the equally long lunar day.

Their TV views and their voices, via their walkie-talkies, are beamed to earth by a radio antenna shaped like an upside-down umbrella, which they have erected on the lunar soil. Eager shutterbugs, they snap away with film cameras, too.

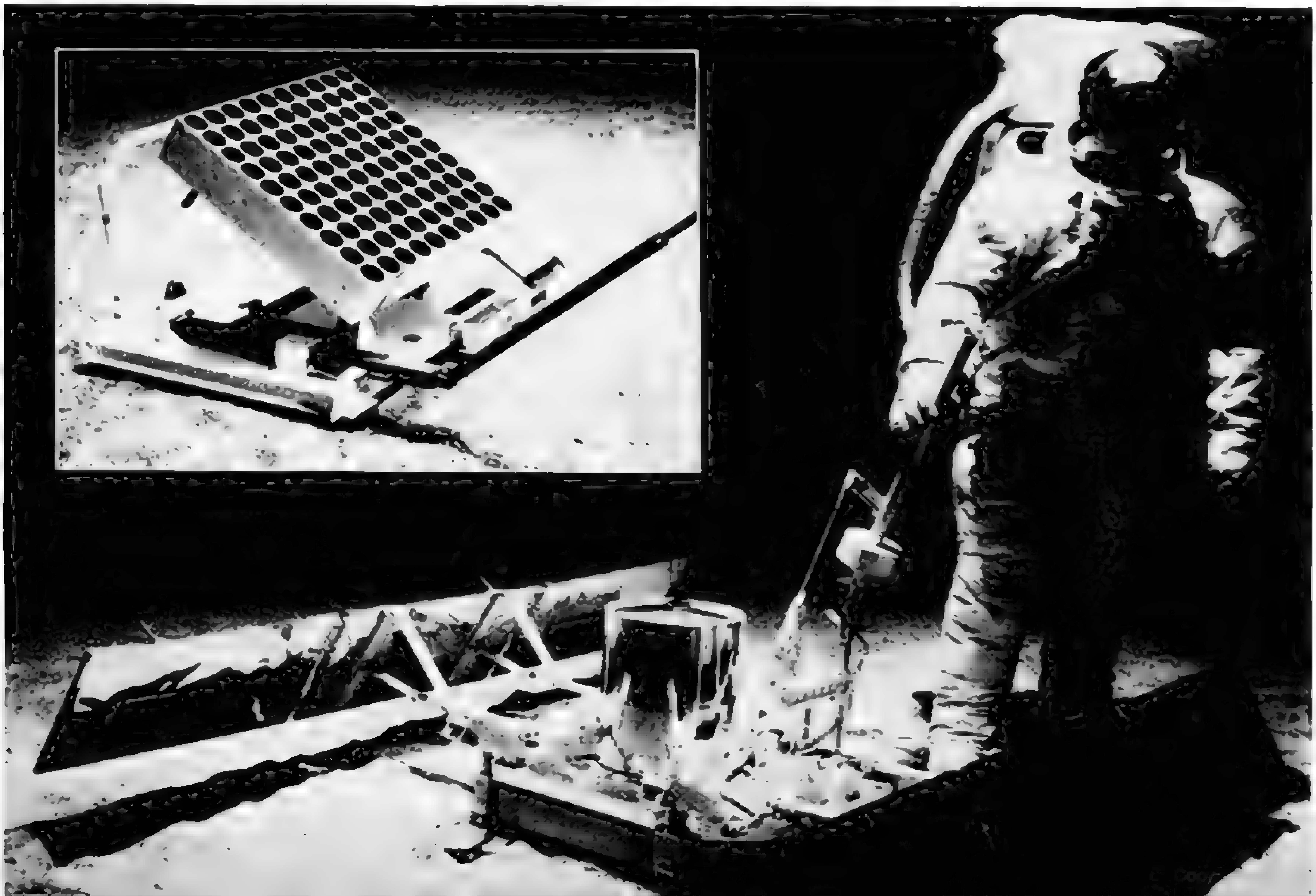
Using long-handled scoops, tongs, and shovels for rock collecting, since they cannot bend over in their suits, they finish filling two "rock boxes" with carefully selected lunar specimens, individually sealed in plastic bags.

Science package for moon. Setting up three scientific experiments, of which two are left on the moon, completes the lunar explorers' busy program.

A "moonquake detector," powered by solar panels, is expected to report any seismic activity to the earth by radio for a

[*Continued on page 169*]

Left on moon's surface will be moonquake detector (large view) and laser reflector (insert). Detector radios quake reports to earth—and is so sensitive that it may record astronauts' footsteps on moon. Solar panels, resembling earth-scraping blades, provide its power. On other instrument's panel, about 1½ feet square, 100 disks bounce back laser beams shot from earth for ultraprecise distance gauging.



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year. It is so sensitive that it may transmit the sound of the astronauts' footsteps as they walk away.

An array of 100 disk-shaped quartz reflectors, inclined to face the earth, will bounce back laser beams shot at it from earth stations. Through its use, scientists hope to measure earth-moon distance with unprecedented accuracy—and also to gauge the precise distance between laser stations on earth, for such purposes as testing theories of continental drift.

A sheet of plain aluminum foil, which the LM crewmen spread on the ground when they leave the craft and pick up again when they return, is a take-home experiment. Later it will reveal the composition of "solar wind" when it is tested for entrapped helium, neon, and other rare gases.

Together the three experiments—called EASEP, for Early Apollo Scientific Experiments Payload—weigh 171 earth pounds, or less than 30 pounds on the moon. Deploying them should take as little as 10 minutes. To avoid overtaxing the first moon men, NASA decided that bringing a more-elaborate science outfit (called ALSEP, for Apollo Lunar Surface Experiments Package) would await subsequent moon-landing expeditions.

In the limited time of their sortie on the lunar surface, the explorers range no farther than 50 to 100 feet from their spacecraft. Returning to it, they spend the remainder of their 22 hours on the moon in resting from their demanding tasks, and in an elaborate prelaunch checkout of the equipment to be used in rejoining the orbiting CSM.

"Fire in the hole." The first manned takeoff from the moon will be due about noon on Monday, July 21. Safety of the astronauts and their precious specimens will depend on the success of the "FITH" launch of their spacecraft's ascent stage. FITH stands for Fire in the Hole, and means that there is no separation of the stage prior to ignition of its ascent engine, nor is there a jet deflector of any sort. Having served its purpose, the now-expendable descent stage serves as a launch platform for the ascent stage, and damage to it from the ascent engine's fiery jet will not matter.

For the first eight seconds the ascent stage climbs vertically, under its engine's 3,500-pound thrust. Then it rather abruptly pitches downward about 50 degrees. Safely above lunar mountains and with no atmosphere to limit speed, it builds up horizontal velocity as fast as possible.

Seven minutes and 16 seconds after takeoff, the Lunar Module is speeding nearly horizontally at almost 3,400 m.p.h., 60,000 feet above the lunar surface. It is safely inserted in an elliptical orbit with a high point of 52 statute miles. If anything should go wrong with it now, the Command and Service Module can come to the LM crew's rescue.

An hour later, the LM ascent stage circularizes its orbit at the high point, by adding a little speed with its small reaction control thrusters. Then a smaller nudge with them adjusts the altitude to put the craft just 17¼ miles below the CSM, and corrects any minor difference in their orbital planes. Now, from behind and below, the ascent stage makes its rendezvous-and-docking with the CSM.

The rest—the start for earth, the long coast through space, the high-speed reentry and splashdown in the Pacific—will be a repeat of Apollo 8 and 10, up to the recovery of the astronauts and the Command Module.

Into quarantine. Then comes the mission's strange conclusion—quarantining the moon heroes and their lunar samples for at least three weeks, in the Lunar Receiving Laboratory at Houston [PS, Oct. '68]. It is a precaution against the chance they might have brought back living organisms—probably unknown on earth and possibly harmful to humans, animals, or plant crops here—although scientists consider it far more likely that the moon lacks any life whatever. Within only a few weeks we may have the first hard evidence, pro or con.

Apollo 11's flight is only a beginning, a scouting expedition. Nine more Apollo landings at different sites on the moon are planned by NASA; the next one, Apollo 12, is scheduled for this November. But the first manned landing on the moon will be an epic achievement—the conquest of the greatest engineering challenge we have ever faced. PS

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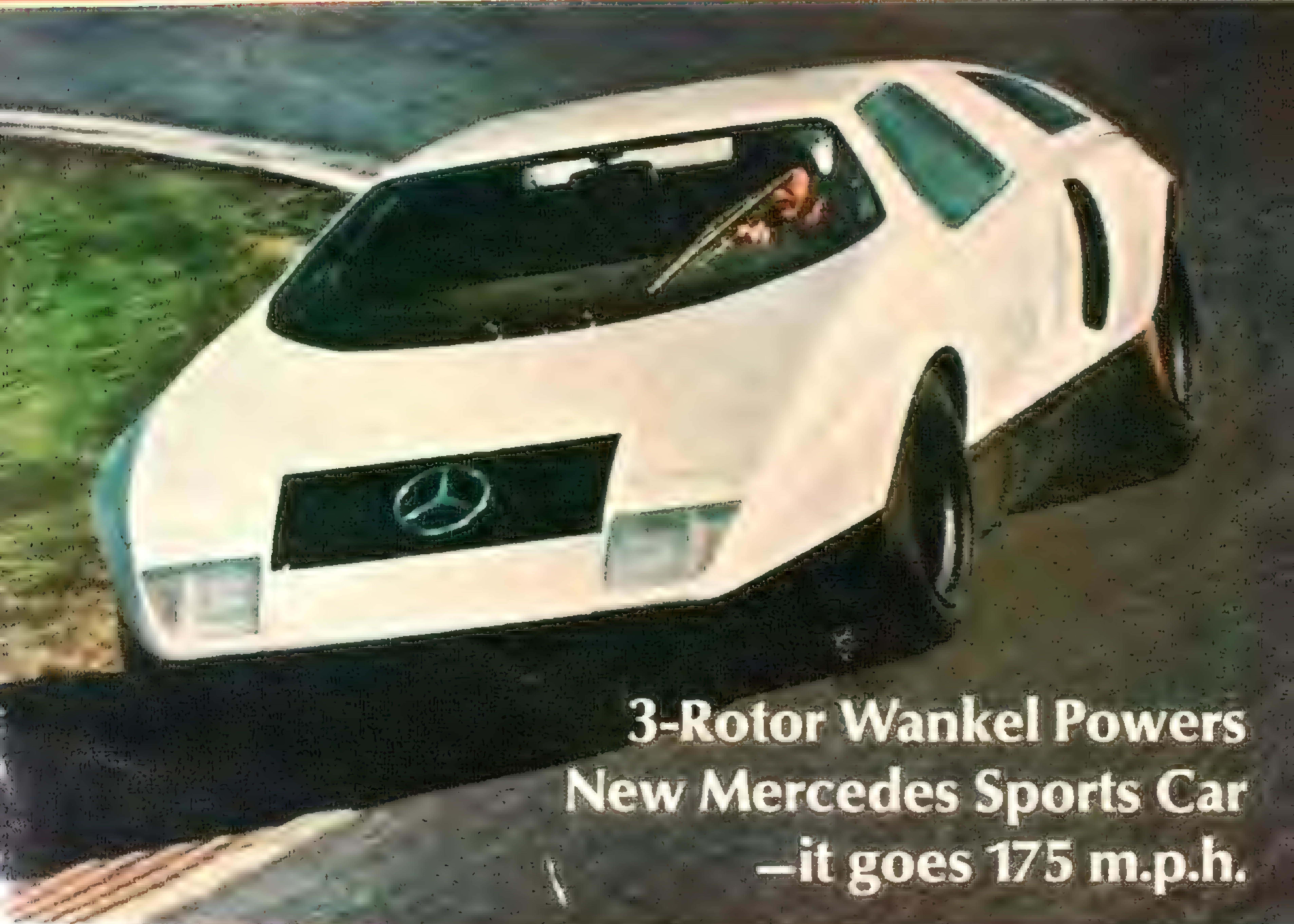

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WHY WE'RE GOING BACK TO THE MOON

By DR. WERNHER VON BRAUN

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

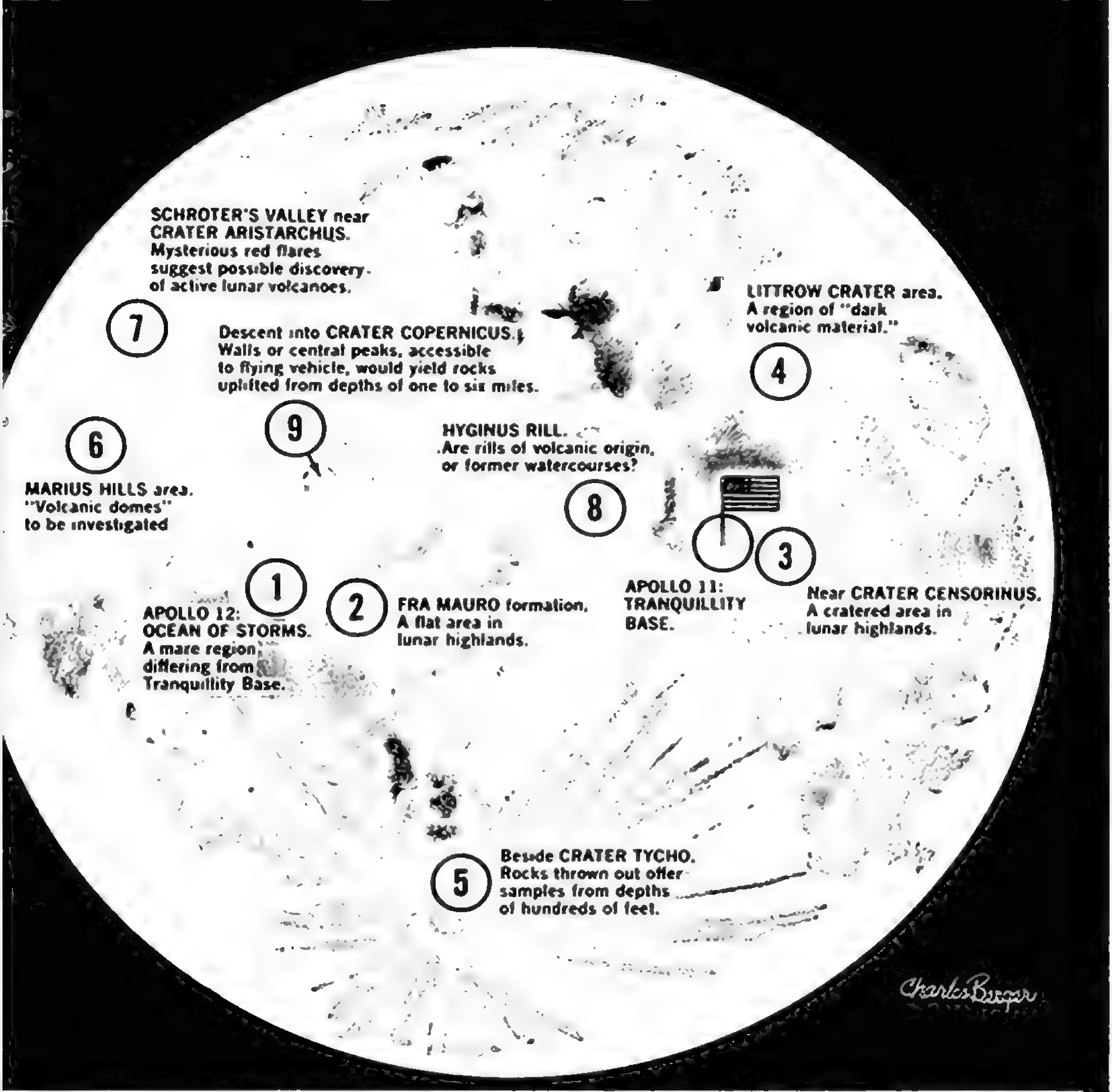
First moon-walkers—Aldrin, and Armstrong (mirrored in Aldrin's visor), at Tranquillity Base—have pioneered way for next lunar landings.

In daring Apollo landings soon to come, many more lunar explorers will follow our first ones—and here a famous space expert gives you a preview of the rewards they'll seek to gain for us

Next month Apollo 12 will head for the moon and a touchdown in the Ocean of Storms. It is the first of up to nine lunar-landing missions, between now and the summer of 1972, planned by NASA to follow up the dazzling success of Apollo 11's pioneers on the moon.

Why are we going back? What more do we hope to learn? First, the moon is a big place—its near side, alone, twice as big as the United States. So far we have landed on one mare—selected for lack o[f] obstacles and ease of approach, with scientific interest strictly taking a back seat. To think that now we know and understand the moon would be like landing i[n] the Mojave Desert and saying that now we know all about the geology and geography of North America.

Still-unexplored reaches hold mysteries of the moon that scientists can hope t[o] solve at last. And probing the moon fo[r]



Sites proposed for next moon landings are these numbered ones, beginning next month with Apollo 12 in Ocean of Storms (1), and reaching climax with descent into majestic crater Copernicus (9). Ranging afar from landing spot of Apollo 11 (flag), sites are all on moon's near side. Far-side landings will await a radio link with earth, perhaps via future lunar relay satellites.

esources of practical value promises rich ewards.

To the moon at bargain cost. There is a urther incentive for mounting more expelitions to the moon right now: We shall ıever again be able to do it so economiːally. This is the reason:

When, in 1961, President Kennedy anıounced a moon landing in this decade as ː national objective, we in NASA had to lecide how many space vehicles to build. Going by the state of the art of rocketry at that time, we expected to have to fly eight to 10 Saturn Vs unmanned, before we could see our way clear to man the supersize rockets. We judged that we might attempt the first lunar landing with the 13th or 14th Saturn V. So 15 of the great Saturn V rockets were actually authorized and built.

Likewise, our spacecraft associates fig-

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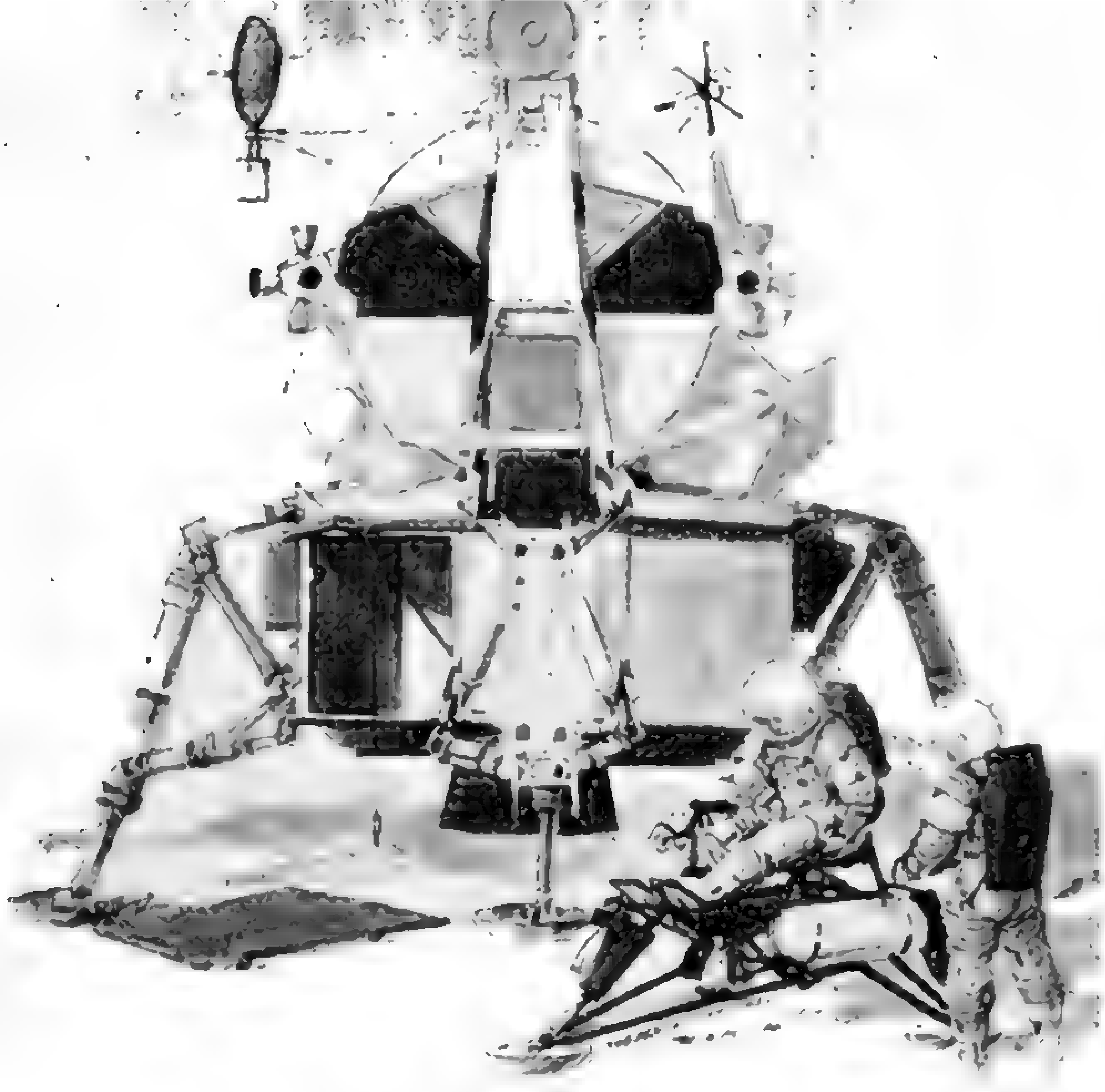
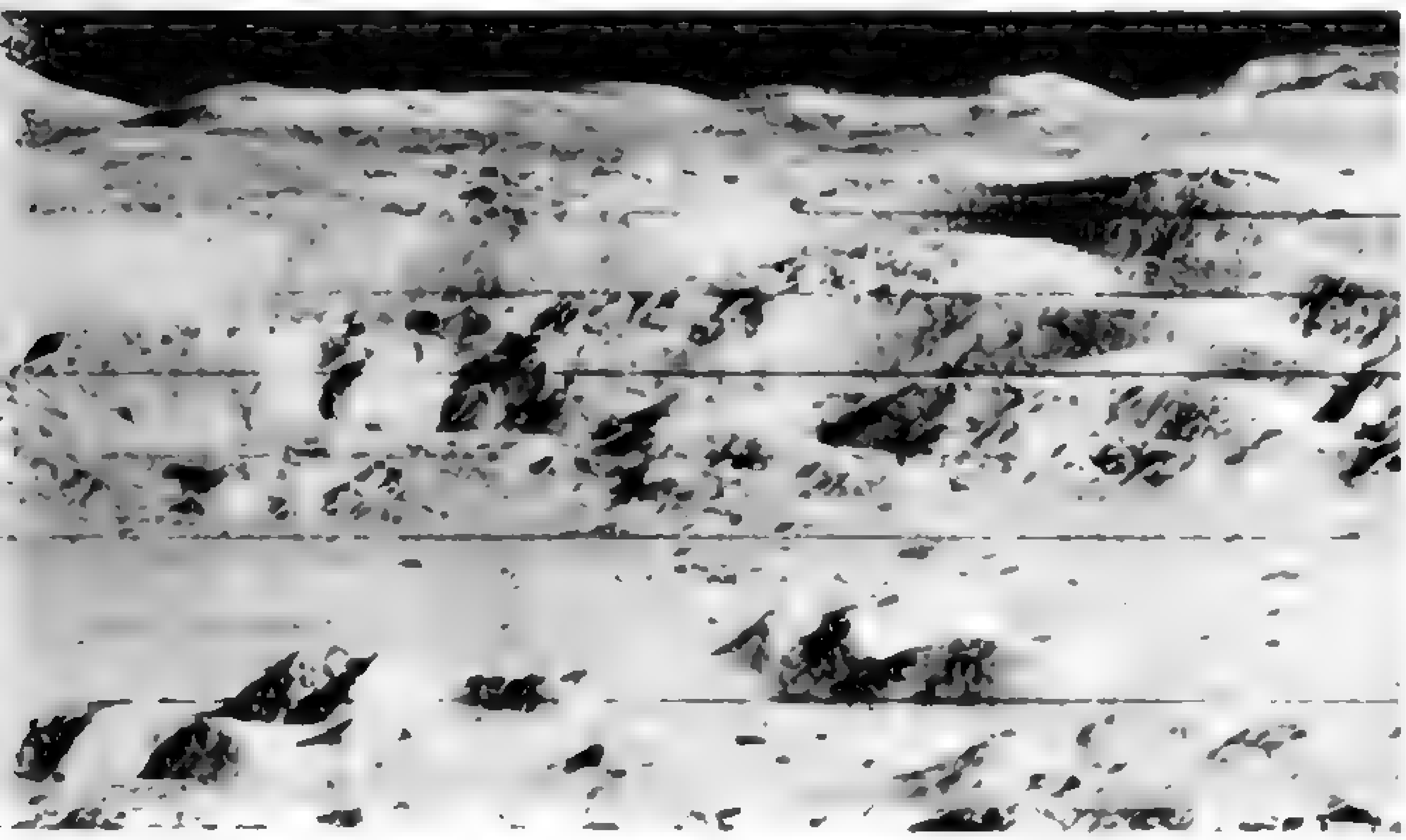
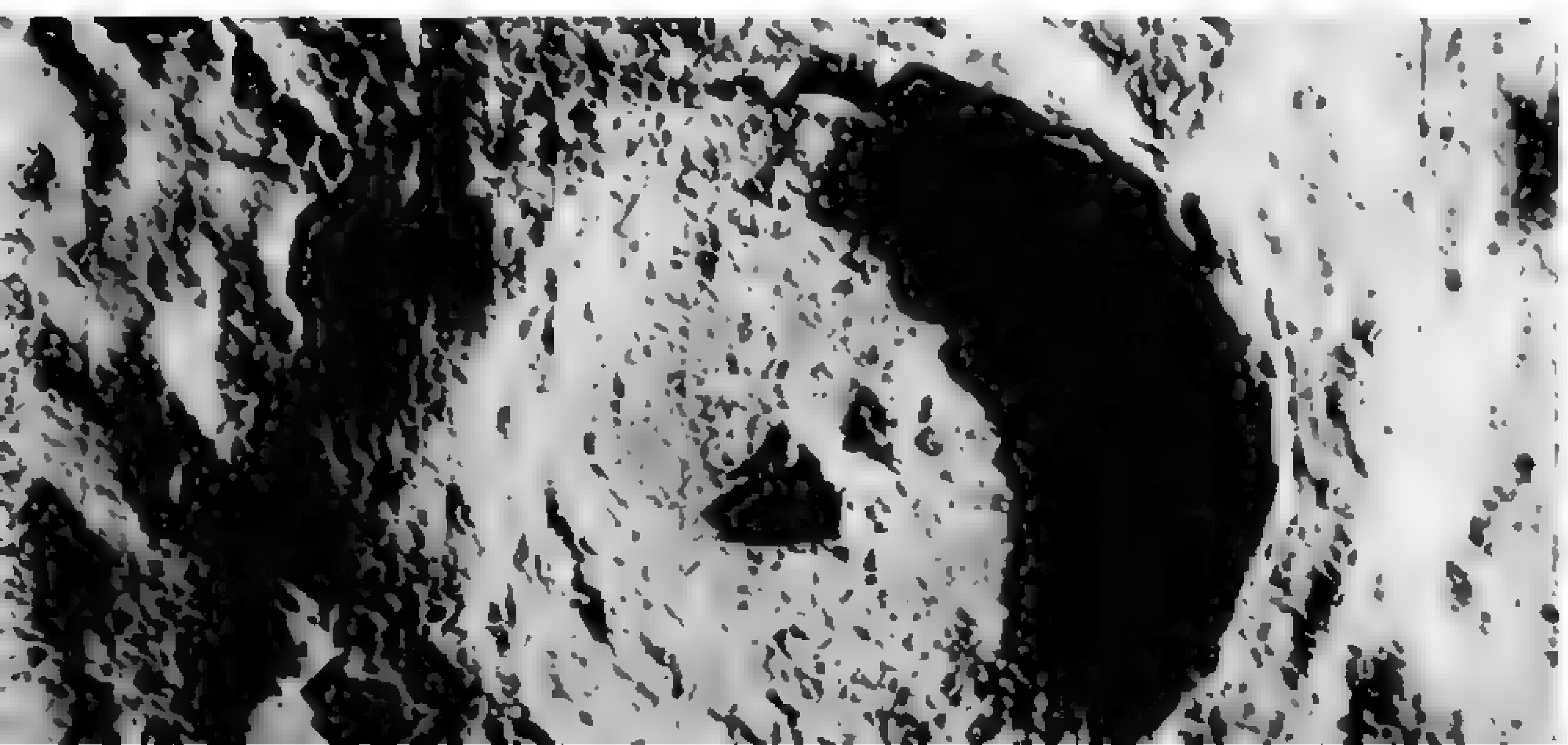


"Augmented" Lunar Module will look outwardly like present one, Grumman drawing shows, but bigger payload can include surface "rover" or pictured flying vehicle—which would be needed at scene below.



Coming landings' boldest target is bottom of two-mile-deep crater Copernicus—viewed in Lunar Orbiter photo that has been called "picture of the century."

Touchdown just outside crater Tycho, pictured in Lunar Orbiter photo, would get samples of moon from hundreds of feet deep by gathering thrown-out rocks.



ured on many orbital tests of Apollo spacecraft modules, before we would dare put an Apollo on top of a Saturn V—let alone fly it to the moon.

As it turned out, only two Saturn Vs needed to be flown unmanned. The third one launched the memorable Christmas '68 voyage of Frank Borman and his Apollo 8 crew around the moon. With the fourth and fifth, Jim McDivitt's Apollo 9 flight accomplished the difficult spacecraft maneuvers in earth orbit and Tom Stafford's Apollo 10 mission performed them in lunar orbit. Thus it was the sixth Saturn V that Neil Armstrong's Apollo 11 rode to the lunar landing.

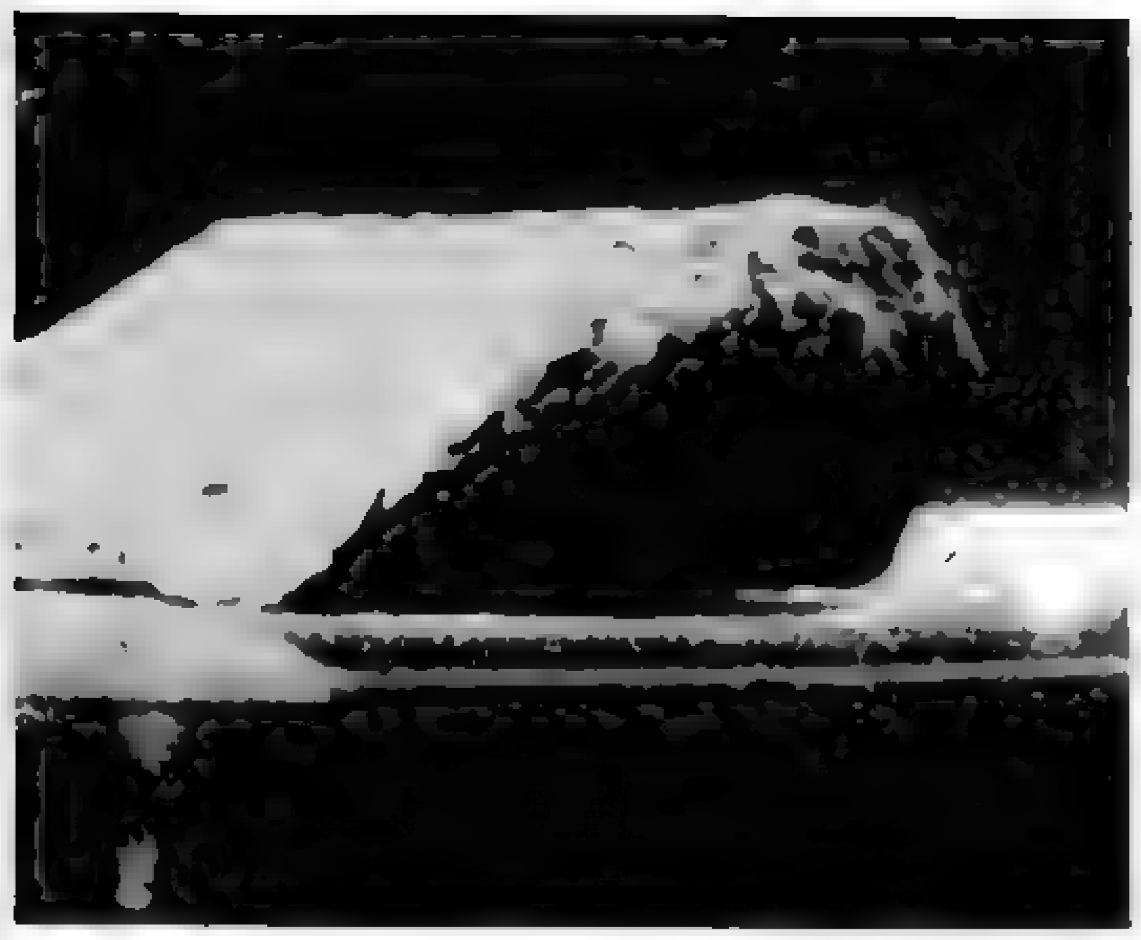
This means that NASA now has a sizable fleet of Saturn V/Apollo space vehicles left over, all designed and built to fly to the moon—and all completely paid for by the American taxpayer. We have the competent industrial and government teams to put them to use, and the well-trained and dedicated astronauts ready and eager to fly them.

NASA turned to the National Academy of Sciences for an independent judgment on the value of a program to continue lunar landings with this remaining Saturn V/Apollo fleet. It will be scientifically worthwhile, the Academy replied after careful study, provided more scientific gear can be landed on the moon; the astronauts' stay time can be extended from one to three days; and sites of particular scientific interest are selected.

Reaching these sites will call for pinpoint landings in difficult topography, and for ability to travel on the lunar surface —as in a roving vehicle that astronauts can drive 10 or 15 miles—to places unsuited for landings.

A new moon-landing craft. Key to all of this was a Lunar Module that could land more weight on the moon. The extra payload could be allotted to consumables for a longer stay, the roving vehicle, more scientific gear, extended hovering, or a combination of some of them.

The present Lunar Module's maker, Grumman Aerospace Corp., was asked to study these requirements, and produced a plan for an Augmented Lunar Module that has, in essence, enlarged descent-stage tanks. As these carry extra propellants, the total launch weight of the Lunar Module increased from 33,000 to 34,250



First moon rocks arrive on earth! Security man shoos photographer aside, right, as Houston lab receives box containing part of Apollo 11's 54 pounds of lunar samples—"worth more than all the gold in Fort Knox," according to NASA's head, Dr. Thomas O. Paine. One of first specimens examined, the three-inch rock above, is called igneous (once-molten) and has glass-lined pits, possibly from impact of micrometeorites. Moon samples are due to go to 142 investigators and their associates for what may well be the most intensive study that any mineral specimens have ever received.

pounds. The added weight, of course, had to be boosted toward the moon by the Saturn V—but it turned out that if the big rocket flexed its muscles just a bit more, it could handle that extra load.

As of this writing, design work on the Augmented Lunar Module (ALM) is almost completed. And nearly 20 companies have prepared competitive proposals for the lunar-roving vehicle.

Meanwhile, a special team has selected a series of proposed landing sites, shown on an accompanying moon chart, for the follow-on missions. They form a moon itinerary to make a scientist tingle with anticipation:

Program for moon explorers. Even the earliest landing sites, still in relatively easy terrain, will contrast with Apollo 11's Tranquillity Base—the first, in the Ocean of Storms, being a mare area of different characteristics.

Then, when the ALM comes along, will follow more-difficult touchdowns at sites of keenest interest:

Are meandering lunar features, called rills, former watercourses or collapsed lava tubes? Inspecting these and other telltale features may settle the controversial question of the role of volcanoes in the moon's history.

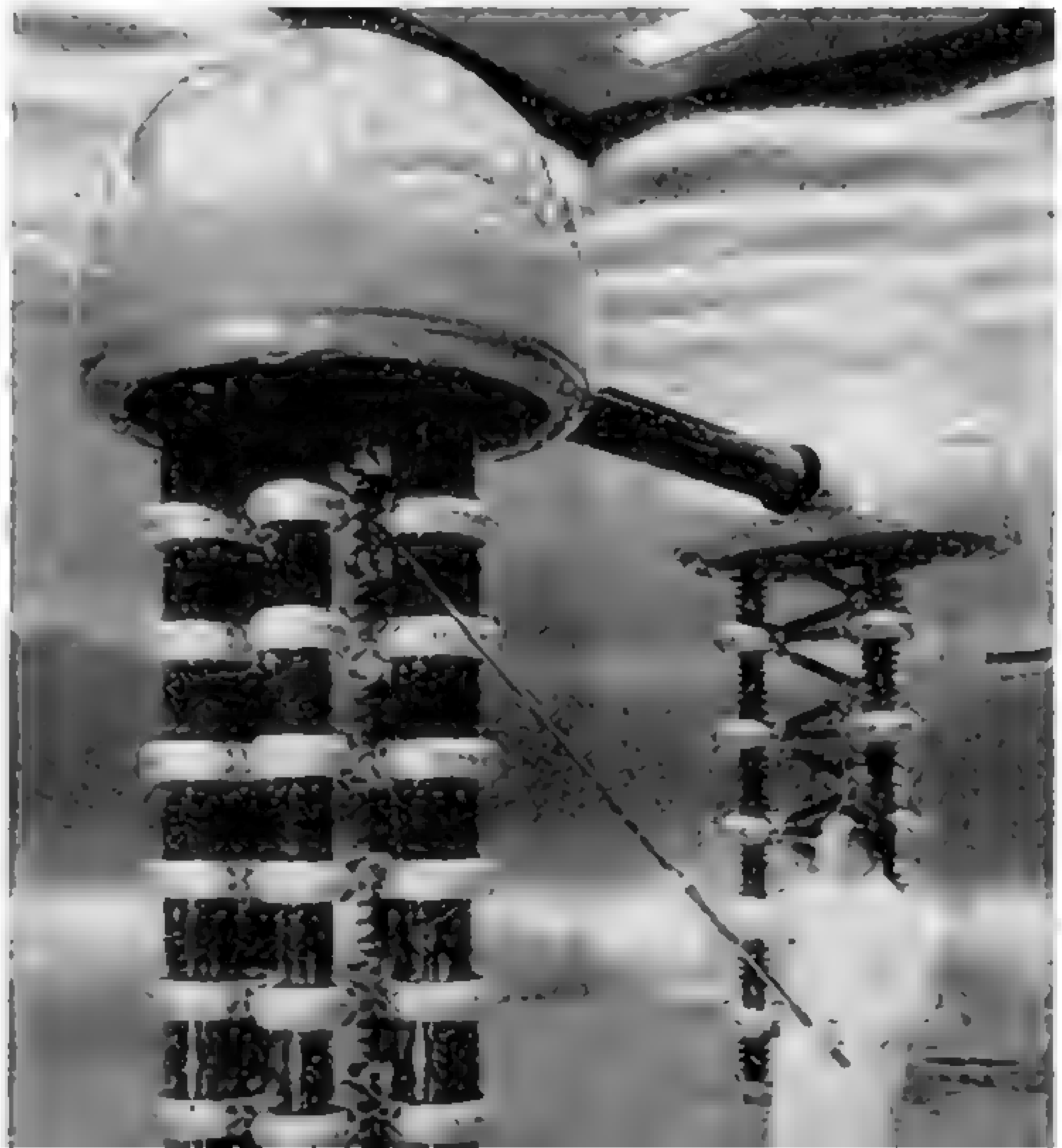
A projected landing at Schroter's Valley near the crater Aristarchus may even make the sensational discovery of still-active lunar volcanoes. Mysterious red flares sighted here have been variously ascribed to a glow called thermoluminescence, or to volcanic action.

Rocks thrown out when the yawning crater Tycho was formed, and collected by landing just outside it, should reveal the composition of the moon's crust to a depth of several hundred feet.

Climax of the program is to be a daring descent to the bottom of the majestic crater Copernicus, "monarch of the moon" —two miles deep, 60 miles across. Its walls and central peaks promise samples of

[Continued on page 218]

Giant 1,000,000-volt electron microscope, biggest in country, is readied to wrest secrets from moon rocks at U.S. Steel lab at Monroeville, Pa. It will peer all the way through specially thinned specimens.



Why We're Going Back to the Moon

[*Continued from page 81*]

rocks uplifted from as deep as six miles. Flying vehicles, needed to reach high ledges and collect specimens, are expected to be ready by the time of this bold venture in 1972.

Mining the moon. Practical rewards of exploring the moon may soon be illustrated by Apollo 11's precious 54 pounds of moon-rock samples—and others to come from the next moon landings.

One of the 142 scientists eagerly awaiting the first specimens hoped to find diamonds in them—microscopic ones, as in rocks around Meteor Crater, Ariz. But it will be more exciting if tests confirm that moon rocks can yield things like water and oxygen—more valuable than diamonds, on the waterless and airless surface of the moon!

Bureau of Mines experimenters and others have demonstrated ways to extract water from lunar rocks if they contain hydrous minerals common on earth. And "mined" lunar water could be decomposed electrically into hydrogen for fuel, and oxygen to breathe or to use as a rocket engine propellant.

Since Apollo 11, it no longer seems at all visionary to look forward to manned lunar bases, exploiting the moon's advantages for such practical facilities as observatories and spaceports. The potential of such bases would be vastly enhanced, of course, if their oxygen, water, and fuel need not be brought for all eternity from earth, but can later on be obtained near at hand.

Apollo 11's feats pioneer the way. A major activity of coming lunar explorers, decking the moon with scientific instruments, was well begun by Apollo 11. The laser reflector it left behind, located by Lick Observatory after a two-week hunt, will measure the wobble of the moon's orbit with new precision. A "moonquake detector" put on the lunar surface reports a fascinating variety of quivers—of which much more will be learned when other detectors at coming sites provide a whole network.

Returning lunar astronauts will continue to be quarantined as a precaution against the remote possibility of "moon germs." Apollo 11 found no sign of lunar life, nor has preliminary examination of

ıs moon samples shown evidence of any in ıe past. But the sterility of samples craped from the ultraviolet-exposed lunar ɔpsoil does not provide ironclad proof ıat deeper-buried strata of the moon, or e that we may possibly find there, will e equally devoid of any microorganism.

Learning moon-walking. For coming oon explorers, one of Apollo 11's most ncouraging feats was to show the ease f walking in the moon's low gravity, ⅙ ıat of earth's. Not every spellbound iewer of the astronauts' prancing steps nd "kangaroo hops" realized he was atching a key scientific experiment. How 5 move about on the moon's surface had een a controversial and much-debated uestion.

One scientist thought grasshopper-like eaps five yards long would be best. Anther, who feared humans on the moon ould have to learn to walk all over again, oubted men could keep their balance ithout the aid of a walking staff—a cumersome handicap to would-be explorers. hose theories evaporated as Armstrong nd Aldrin stepped forth on the lunar surace, cautiously at first and then with rowing confidence.

Hopping with feet together did work, ıey reported—but easiest of all was that trange slow-motion lope that now appears ɔ be the lunar version of normal steps on arth. In a few dramatic moments, before V watchers' eyes, man learned to walk he moon.

The lessons will soon be applied by ıpollo 12—which will try to land near our ınmanned soft-landed Surveyor 3 spaceraft of 1967. This time the astronauts ill moon-walk much farther from their raft, perhaps 1,000 feet or more. Given a inpoint landing, that may allow them to isit and inspect the Surveyor, and even ring back a detached part to study. earning what happens in two years to apaaratus exposed on the moon would help ngineers design long-lived instruments to ut there.

Apollo 12's astronauts will make two orties on the lunar surface—each longer han Apollo 11's single 2½-hour one. hus will begin the lengthening of time llowed for lunar exploring—which will inrease, more and more, with succeeding xpeditions.

DECEMBER 1969 50 CENTS

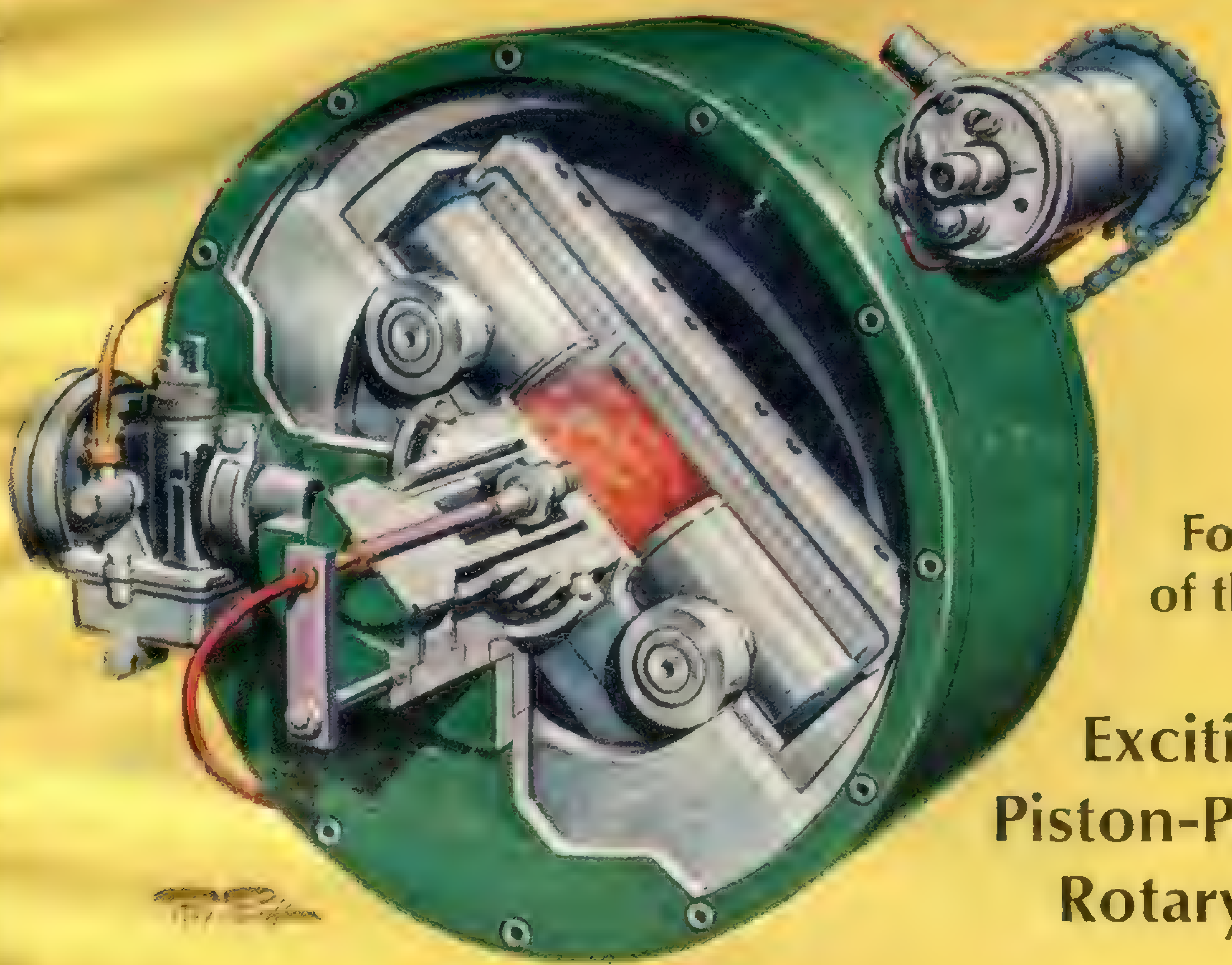
Popular Science

THE What's New MAGAZINE

How You'll Play Color Tapes on Your TV Screen

Streamliners Without Wheels

By JOHN A. VOLPE
Secretary of Transportation

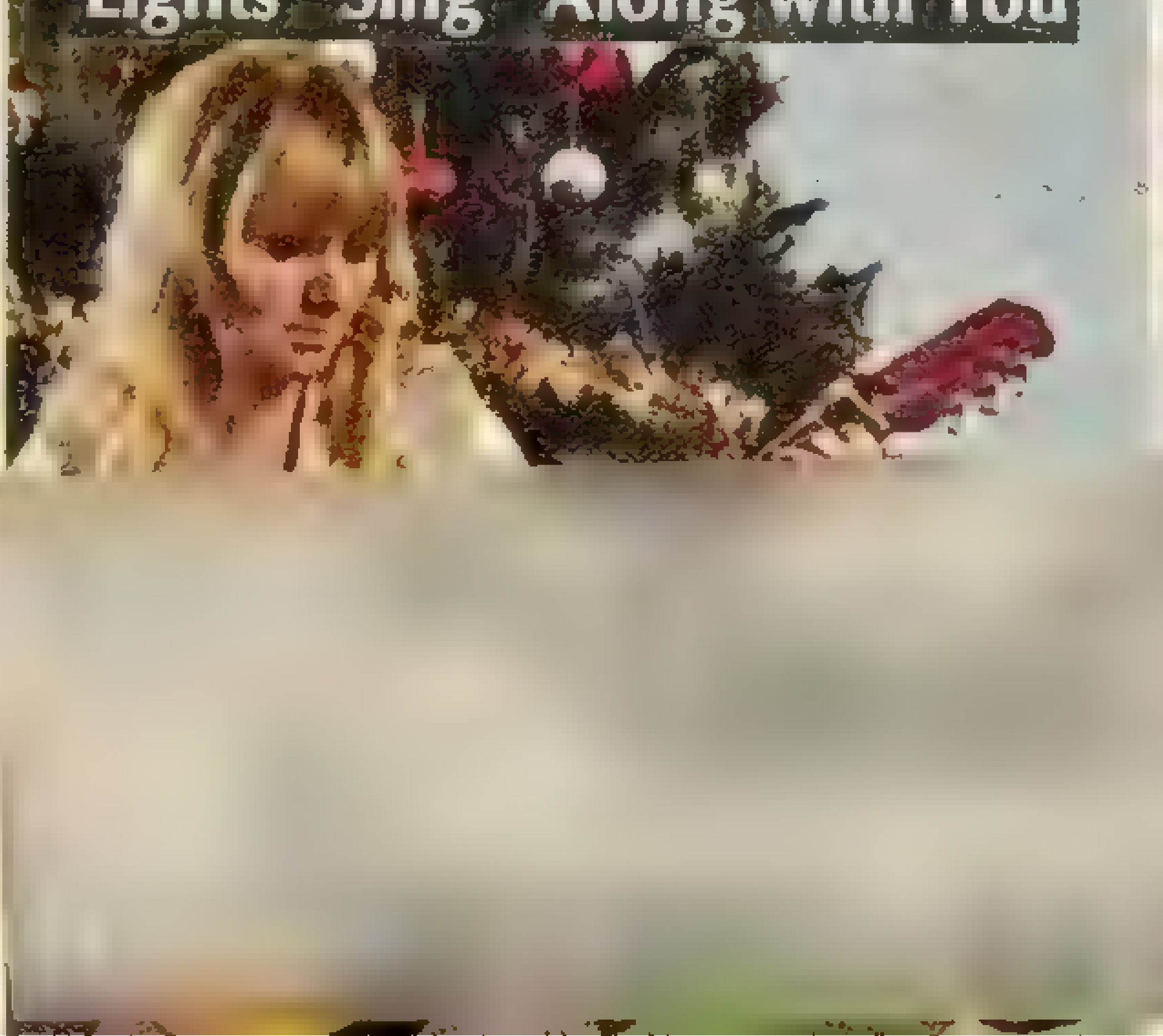


For Your Car of the Future?

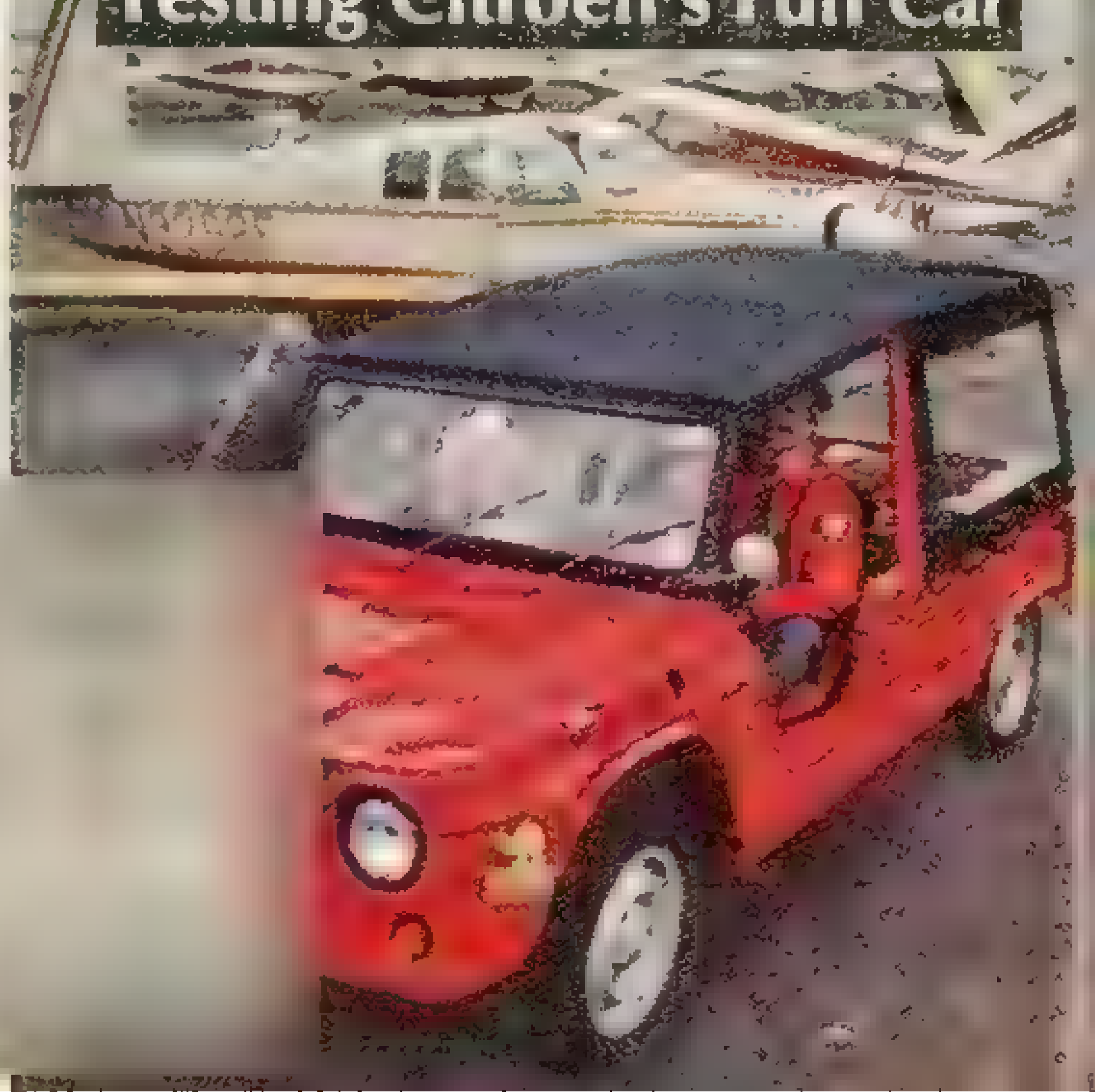
Exciting New Piston-Powered Rotary Engine

Build a Snowmobile Shelter

Lights "Sing" Along with You



Testing Citroen's Fun Car



Wonder products you never imagined from FACTORIES IN

Exotic hardware and fantastic materials will emerge from orbiting workshops where zero gravity and high vacuum will rewrite the "ground" rules of manufacturing

By DR. WERNHER VON BRAUN
Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

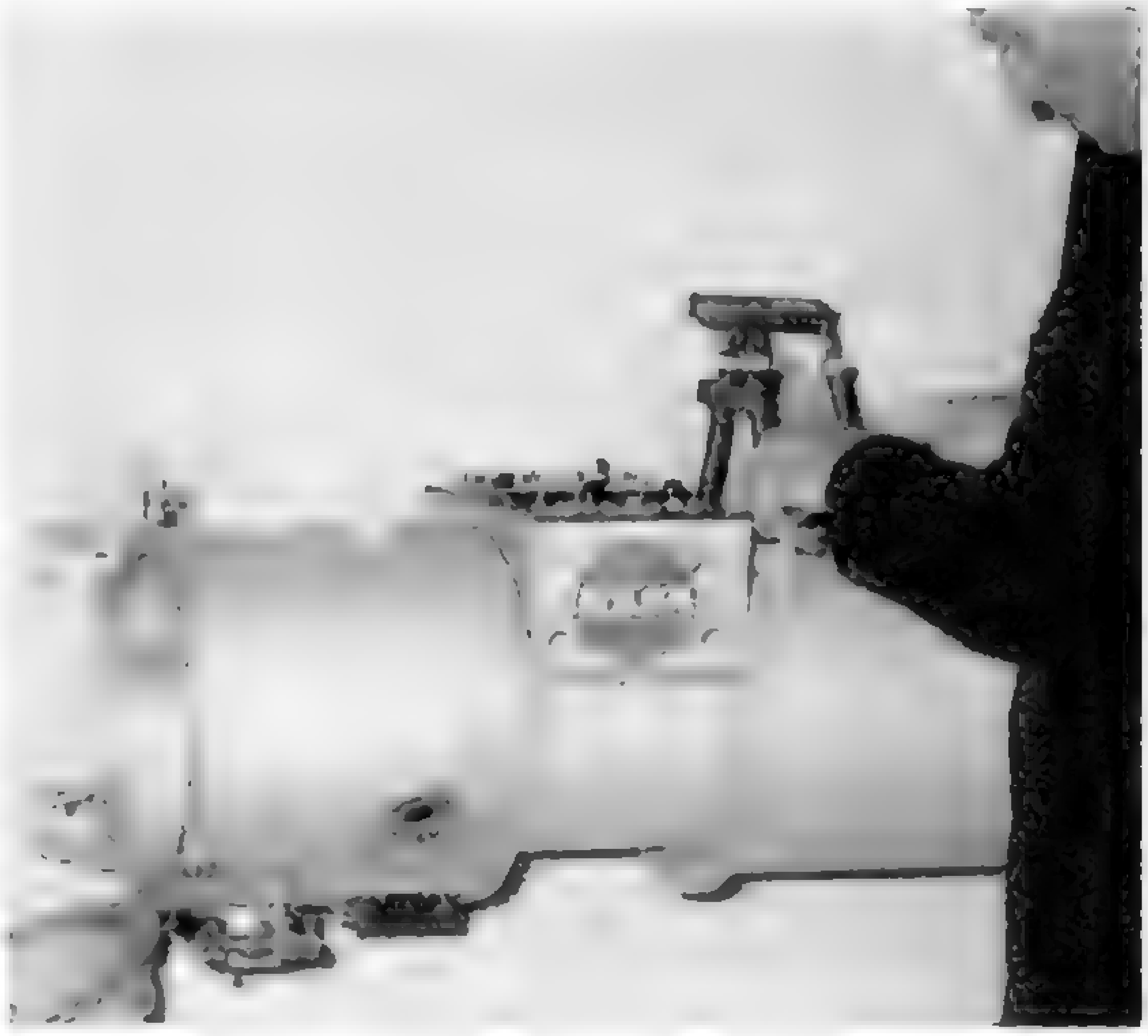
Practical uses of earth-orbiting spacecraft—exemplified thus far by weather, communications, and navigation satellites—may well extend in coming years to supplying us with tangible and valuable goods "made in space."

Experiments now being planned by NASA will explore some of the fantastic possibilities of conducting manufacturing operations in orbiting factories. Exotic new materials, improved forms of others, and novel manufacturing methods are promised by taking advantage of conditions inherent in space—especially zero gravity and high vacuum.

"A steel foam almost as light as balsa wood, with many of the properties of solid steel," is foreseen as one possibility by NASA's Dr. George E. Mueller. Other examples include perfect-sphere ball bearings, solid or hollow; composite materials that cannot be made on earth; and strainless blanks for large astronomical-telescope mirrors. The outer-space products could be returned to earth in a heat-shielded capsule fashioned after the Apollo Command Module or in NASA's latest objective, the reusable earth-to-orbit shuttle craft.

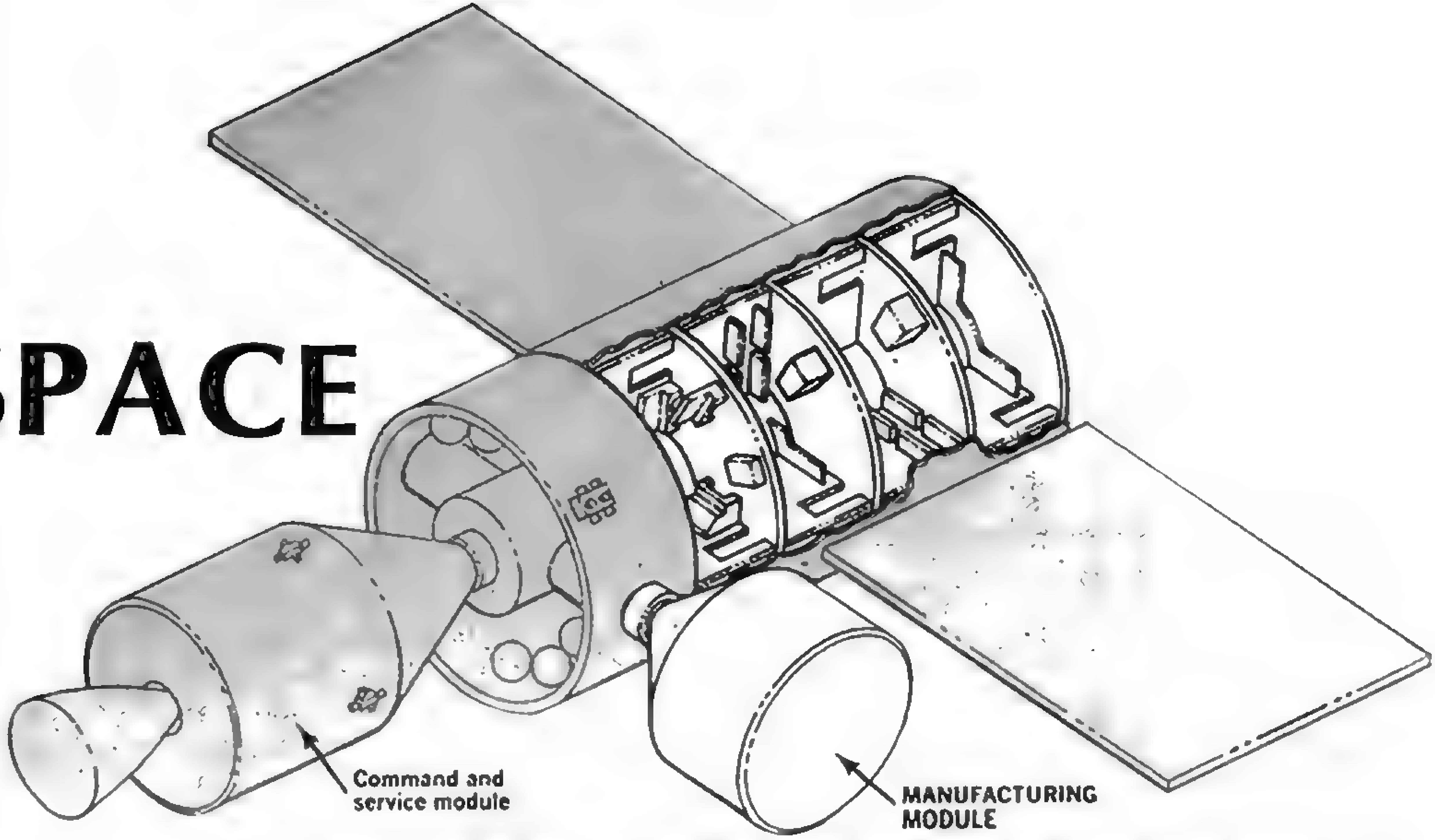
First hardware built for trials. To come to grips with the exciting prospect of zero-g manufacturing, and its problems, the Marshall Space Flight Center has developed a 70-pound Space Manufacturing Process Chamber (photos below) that is scheduled to fly on one of the two manned Saturn Workshops of the Apollo Applications Program.

The chamber will be mounted on an inner wall of the Workshop's Multiple Docking Adapter—where astronauts can work with it in a "shirtsleeves" environment, while its interior will be vented to space for experiments in a vacuum. It is designed to accept experiment pack-



"Space Manufacturing Process Chamber," pictured in three photos, is first actual hardware built to try out making products in zero gravity and vacuum. It will be carried aboard a coming Saturn Workshop.

SPACE



"Manufacturing Module" will be docked as shown to future NASA space station. Chambers on its inner walls will be enlarged versions of the one in photos below.

ages for trials including zero-gravity welding, brazing, heating and casting metals, and crystal-growing.

An electron-beam gun, operable for about 10 minutes on its battery pack, will supply heat for welding and some other tests. A trial brazing to join tubes will use a pyrotechnic heat source.

For NASA's future modularized Space Station the plans for zero-g manufacturing research are more ambitious. In all likelihood there will be a separate Manufacturing Module, carried to orbit in one of the logistics supply flights, and plugged into the main crew-quarters module as pictured above. The Manufacturing Module will be a rather spacious manned laboratory, with its own capability for minor modifications and repair.

How zero-g changes the rules. Ever since Bronze Age man learned to melt

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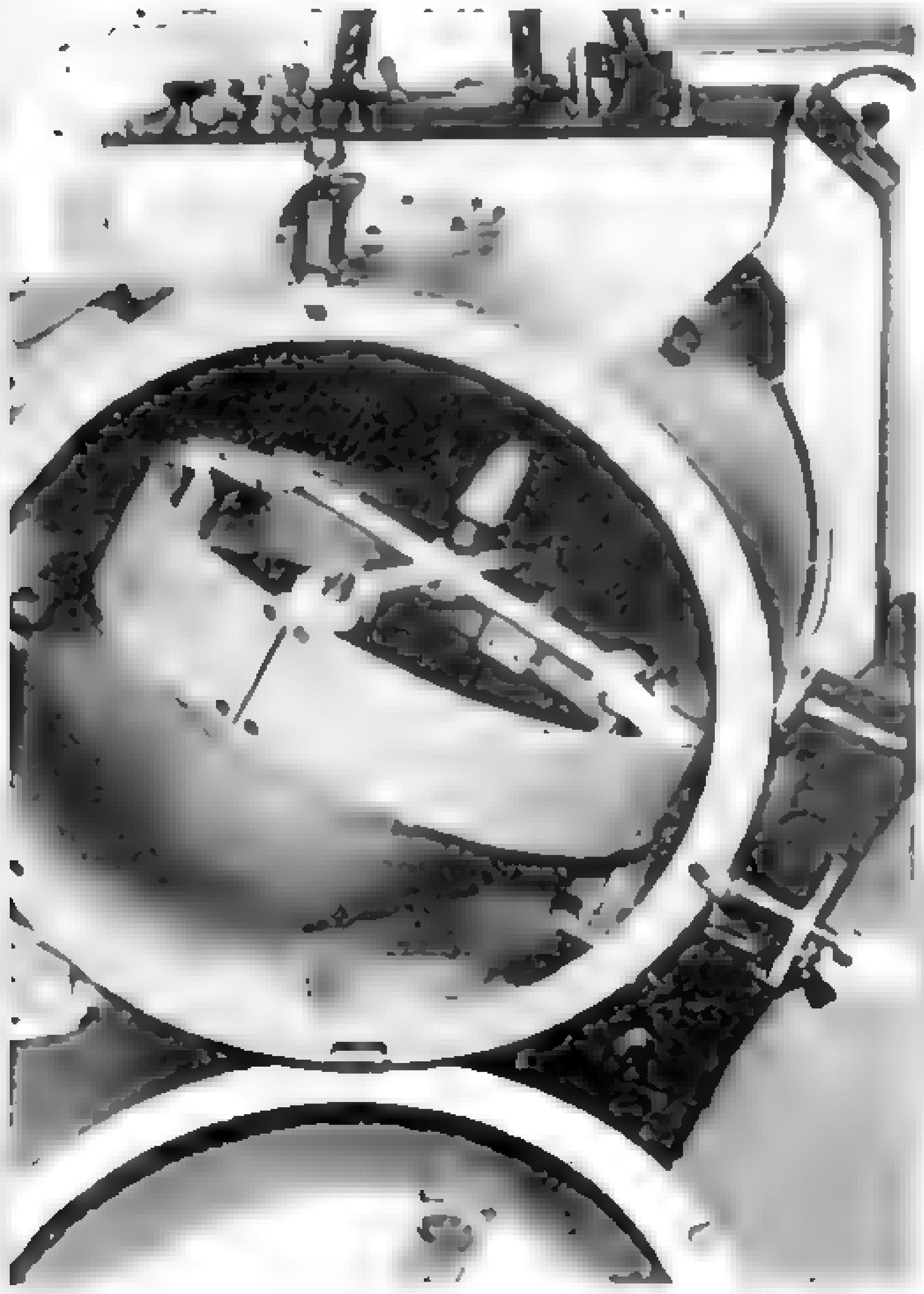
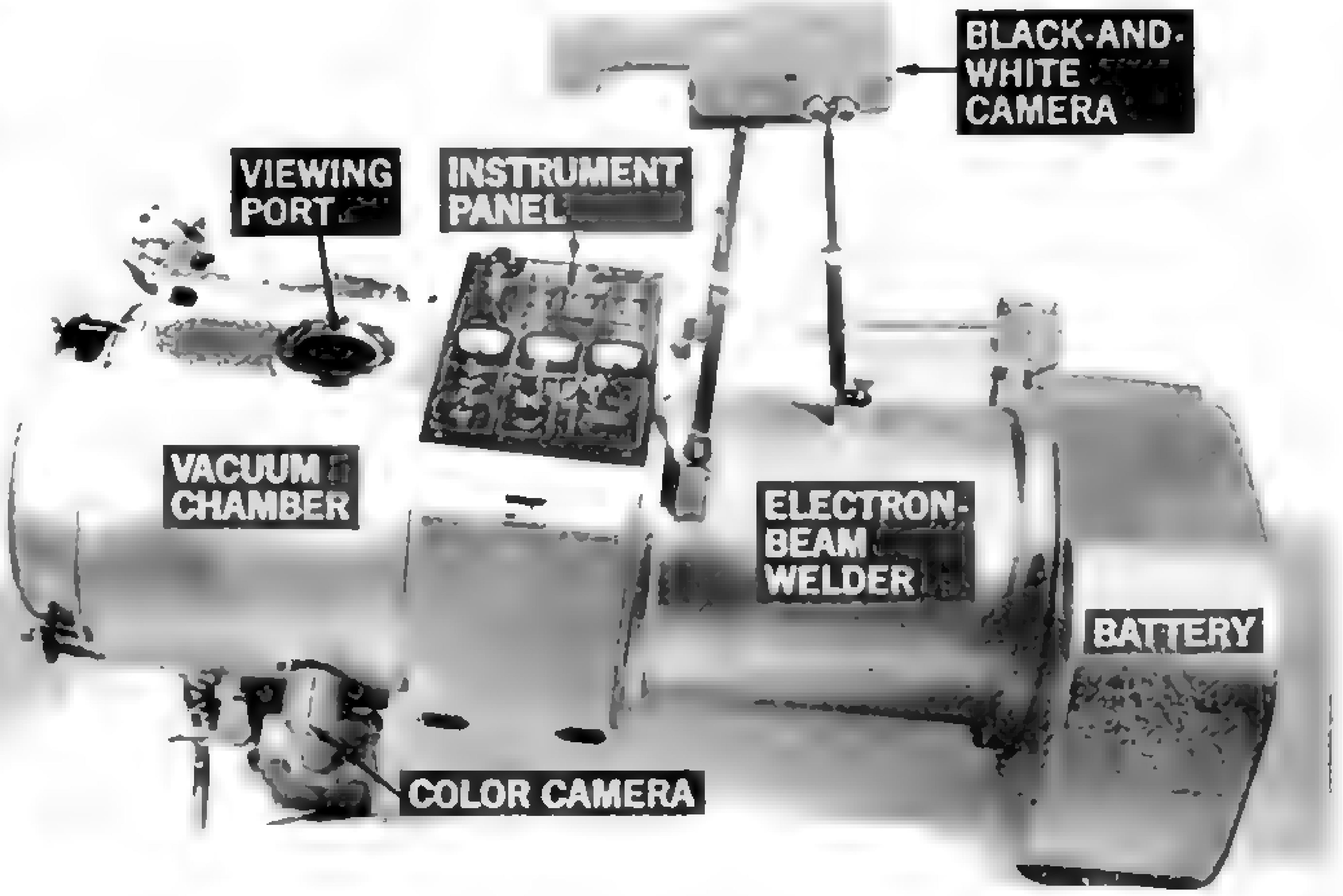
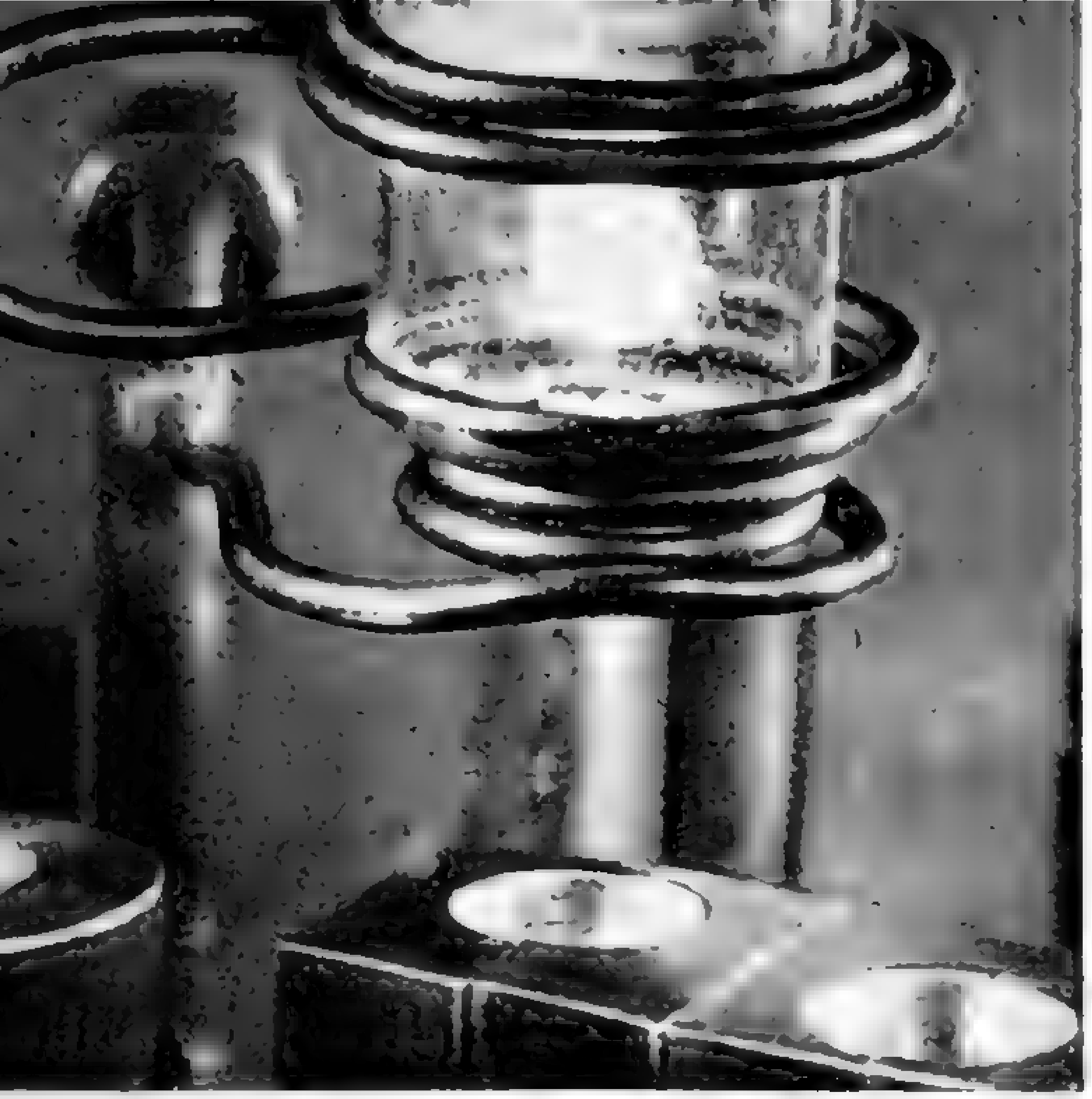
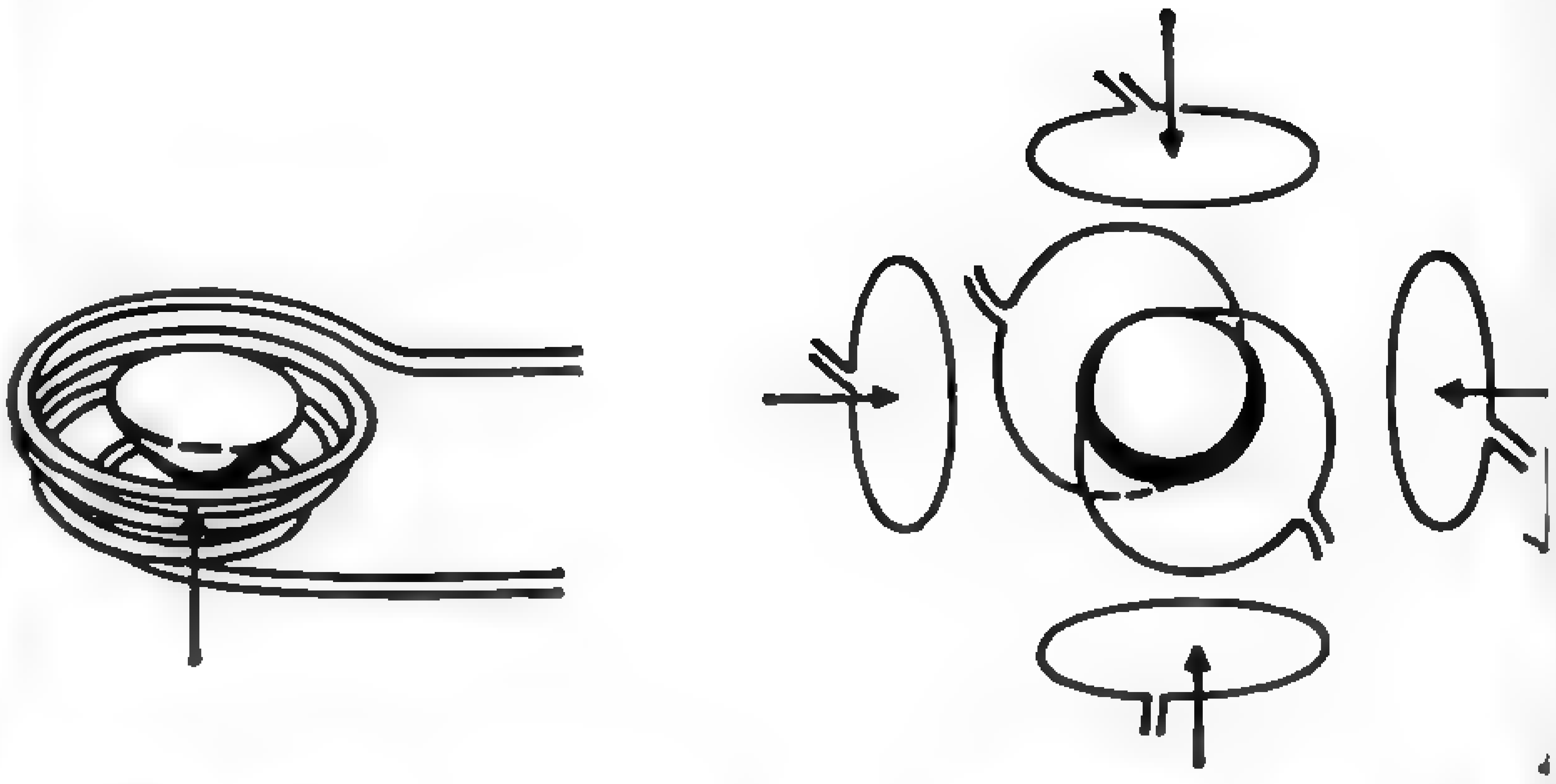




End view of opened chamber shows one of interchangeable experiment packages inside. This one, for zero-gravity welding, brings various materials on quadrants of rotating wheel before an electron-beam gun. Side view of 70-pound chamber—about 30 inches long and 12 inches in diameter, overall—shows cameras, mounted at observation ports, that will continuously record what is happening within.





Levitation melting, a "natural" for space, floats metal in a vacuum to avoid contamination from crucible or air. Method is limited on earth to small amount that can be suspended by high-frequency coil—as in photo at Allegheny Ludlum Steel Corp. research center, and adjacent diagram. In zero-g, batch can be of many pounds—and coils (other diagram) merely adjust its position.

down metals and mix them, our metal-forming experience has been affected by two ever-present phenomena due to gravity—buoyancy, and heat convection.

When we make a casting, we provide a "riser" so that gas bubbles, oxides, and other impurities in the melt can get up and out of the mold. Melting down a mix of metals, we find that as the fluid cools and hardens, only a certain percentage of each metal will wind up in the alloy. The insoluble excess will separate and rise to the top, or sink to the bottom, according to comparative specific weights.

Likewise, if we stir sand and water in a glass jar, the sand soon sinks to the bottom, with the water on top of it.

All this is not so in the zero-gravity environment. Water and sand stay mixed, for hours and even days. The various ingredients of a multi-metal alloy remain mixed, too, regardless of solubility limits. The gas bubbles in a casting do not rise to the top. These simple facts open the door to a myriad of new possibilities.

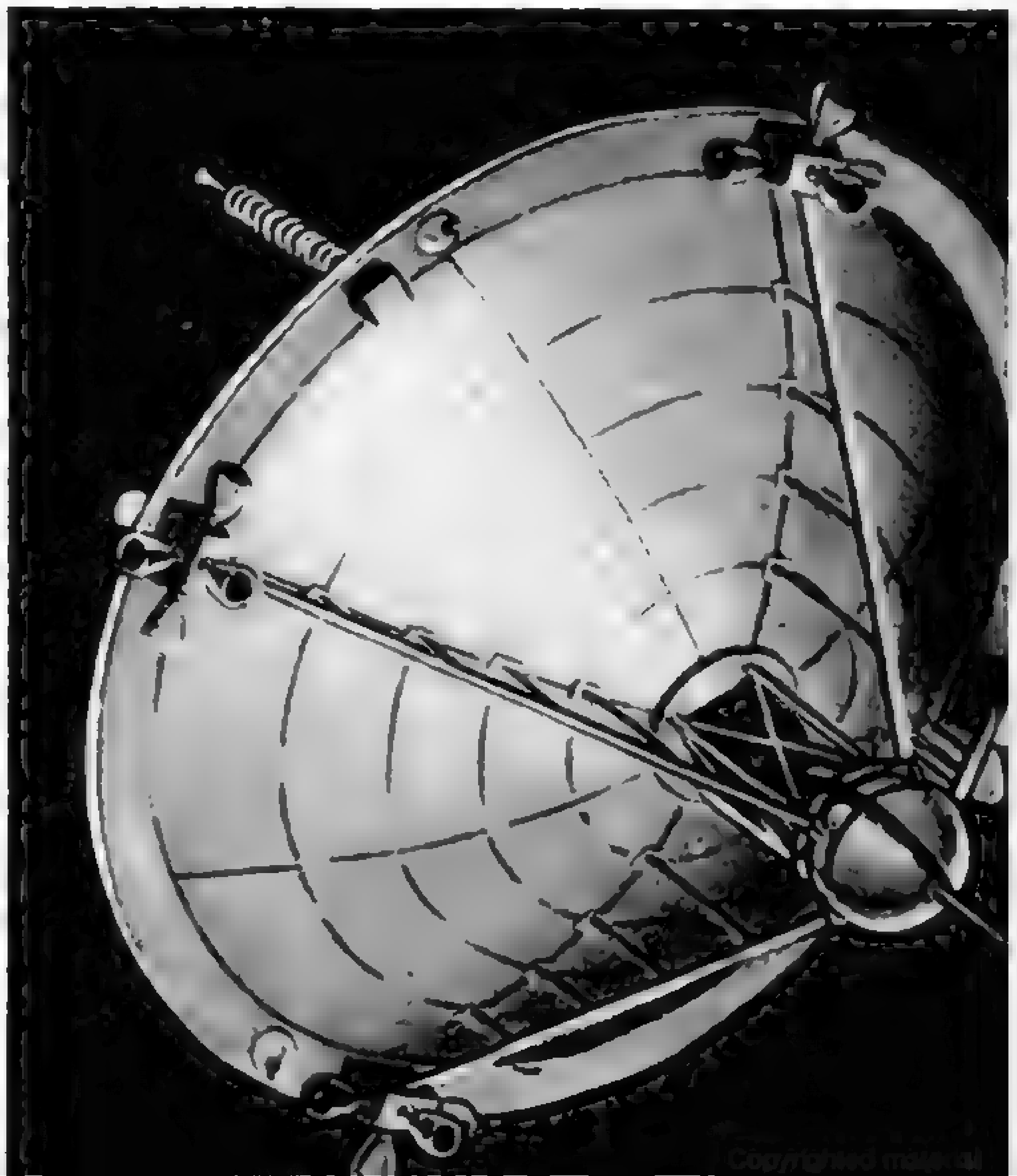
Making lightweight metal foam. Suppose we fill a mold with a carefully packed load of tiny spherical pellets, some of which are stainless steel, while others consist of a material that gives off an inert gas when heated.

We melt down the pellets, and let the mix harden, all in zero gravity. The result will be a stainless-steel foam—with completely closed, non-interconnecting cavities. Thrown in the water, the metal foam will not soak up water like a sponge, but will present a watertight outer surface. If its ratio of gas cavities to steel was large enough the foam would even float.

Shells of deep-diving submersibles, for one example, would benefit from the use of this lightweight structural material. While the cavities do not improve the strength-to-weight ratio of a metal under *tension* (as in a steam boiler), there is a great gain under *compression,* due to the larger cross section for the same weight.

We could go a step further. In zero gravity it would be possible—say, by spinning the bubble-filled melt—to produce a casting of varying density, tailored to a specific need. In the design of turbine blades, for example, it is of utmost im-

Orbiting solar furnace of 15-to-20-foot diameter, able to melt a mass of 300 to 500 pounds, is envisioned by North American Rockwell Corp. designers as nearby adjunct of a future big-scale space factory.



portance to make the tips as light as possible, in order to reduce the centrifugal loads on the blades' feet. Zero-gravity melting of the blank (from which the final blade may still be forged for greater strength) can provide "programed density" along the length of the blade.

For the radiation shielding of electronic equipment—important for the "hardening" of missile sites and for use of electronics near nuclear reactors and in high-altitude aircraft—the blending of materials of different densities, possibly in a plastic matrix, offers great promise.

Instead of gas-releasing pellets, the original pellet package can contain reinforcements—such as high-strength crystal "whiskers" (PS, Feb. '69) or wire filaments. They may be oriented according to the load pattern foreseen for the cast.

Applying another principle in space may permit us to cover a central mold with several layers of metal or nonmetal coatings. Some fluids tend to "wet" other surfaces and cover them completely. Thick layers, which would drip off at one g, could be built up at zero g. This "adhesion casting" technique might be applied for coating nuclear isotopes or optical components.

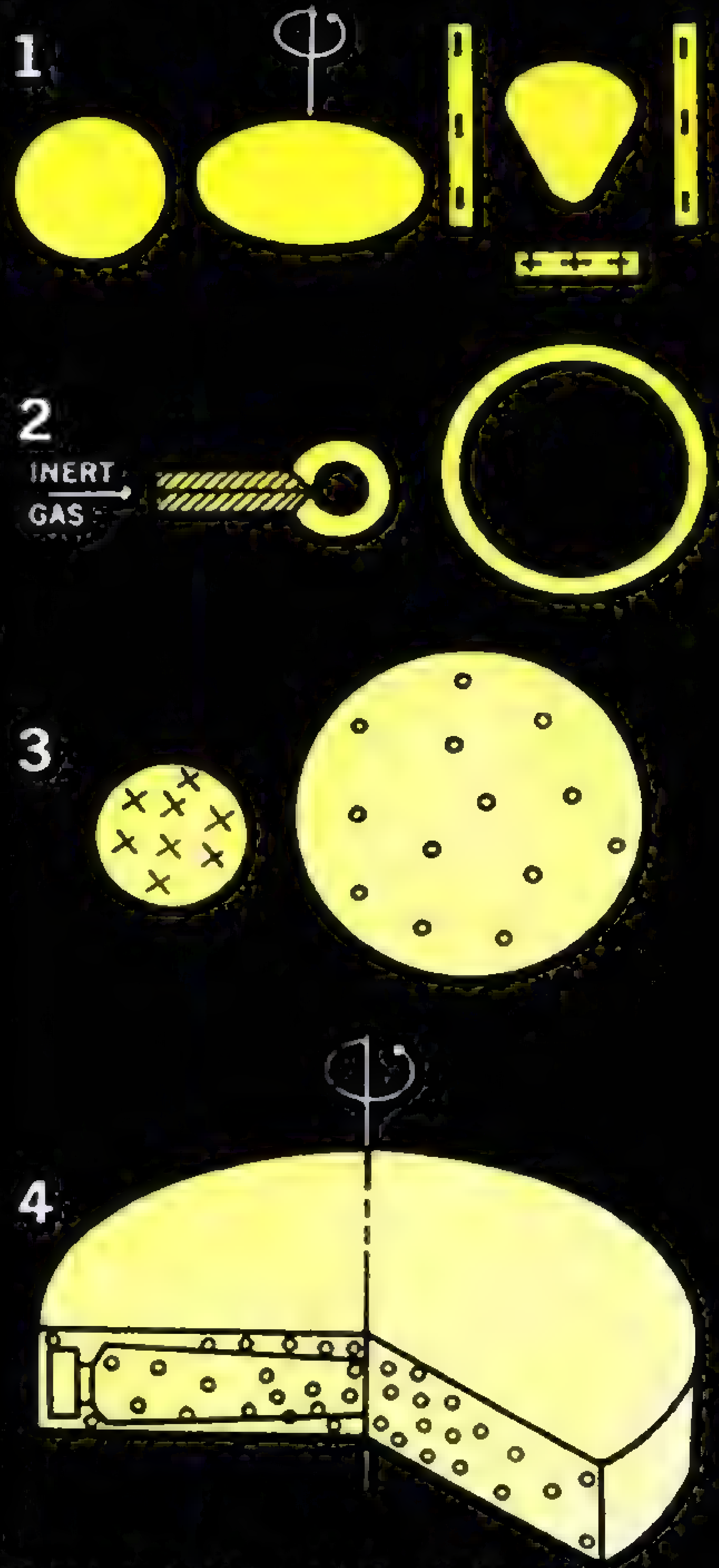
Shaping free-floating metal. In many cases we may not even need a mold. If we melt down a piece of metal as it floats in zero gravity—while kept in position, for instance, by induction coils—it will promptly become a perfect sphere. (Its surface snaps into that shape at a speed on the order of several hundred m.p.h.)

By putting a spin on that sphere, we can turn it into a paraboloid. By exposing it to an external electrostatic field, we could transform it into a teardrop—or any of a multitude of other configurations. The still-hot and moldable workpiece could also be shaped by a magnetic field, or by gas jets impinging on it. All these external effects, as well as the heating and cooling sequence, could be precisely controlled by a preprogramed computer.

In words of Hans F. Wuenscher, the imaginative originator and head of the zero-gravity manufacturing program at the Marshall Space Flight Center, space manufacturing will thus substitute the tool of "energy management" for conventional tools such as drop hammers, milling

[*Continued on page 181*]

Strange Things You Can Make in Space



Zero-gravity factory can introduce novel processes like examples pictured:

1) Floating melt solidifies into perfect sphere, as for ultra-precision ball bearing—or into other wanted shapes, if spun or subjected to electrostatic field.

2) Blowing bubbles of metal can produce hollow ball bearings—lightweight and precisely round—for jet engines, tilt wings, and large radar antennas.

3) Steel almost as light as balsa wood results when volatile pellets in melt (x's) turn into evenly distributed bubbles (o's). Product, when solidified, is a metal foam.

4) Jet-engine compressor blades desirably light at tip and dense at base could be cut (as outlined) from varying-density material, made by spinning a melt of bubble-containing metal. Resulting blank grows denser (has fewer bubbles) toward rim.

Wonder Products from Space Factories

[*Continued from page 75*]

machines, and cranes. Computer tapes will manage the energies required for heating and cooling; for electrostatic, magnetic, and inertia fields; and for gas jets used to deform the workpieces or to move them from one work station to the next. Zero-gravity casting, Wuenscher believes, may permit accuracies on the order of a few angstroms—attainable by classical methods only with great difficulty and at high cost.

Where does the high vacuum of space come in as an advantage for an orbiting factory? For one thing, it makes space the cleanest place there is.

Today's researchers resort to "levitation melting" to make ultra-pure alloys, uncontaminated by a crucible or the air. Suspended in a vacuum by a high-frequency coil, the metal "floats" without touching anything, while it is melted. But on earth this works for only a tiny batch of tens of grams. In the vacuum of space—where any amount of metal floats freely—an ultra-pure batch of 20 pounds or more could be melted and cast.

Will space products repay their cost? Whether space manufacturing can pay its way will depend chiefly on the success of NASA's efforts to develop a truly reusable earth-to-orbit space shuttle—now firmly planned to be available for operational use in the late 1970s. This shuttle is designed to slash present space-transportation costs drastically.

For a long time, even with this economical earth-orbit logistics system, space manufacturing will appear attractive only where substantial gains in quality can be attained for critical low-weight construction elements. It would be foolish to carry bridge girders to orbit and back to have their welds improved.

But suppose we could produce, by zero-gravity casting, a jet-engine turbine blade that could be reliably operated at a temperature 200 degrees hotter than the best blade made on earth. All the jetliners in the world would promptly benefit—in the form of increased cargo, range, or both—from the resulting fuel saving. And the savings accrued over years of operation would easily repay the cost of a blade 30 or 50 percent more expensive because of its orbital origin. PS

1970

Popular Science

Your First Look at Detroit's Mini-Compacts

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- Electronic Stethoscope
- A Prize-Winning Foamboard Chair

The Strange World of Magnetic Bubbles

Surprising Facts We're Learning from the

Intriguingly different from what anyone had expected, the lunar rocks and other evidence gathered by our Apollos boost hopes of solving the mysteries of the solar system

By
DR. WERNHER VON BRAUN

Director of NASA's Marshall Space Flight Center, Dr. von Braun has a special place in history as head of the Saturn V team whose rockets have put our astronauts on the moon. As our Consulting Editor on Space, he contributes frequent articles on exciting developments in the space program.

Puzzling recordings of Apollo moonquake detector, watched as they come in at Houston by Dr. Gary Latham (left), now are explained by Apollo 12 test that made the moon ring like a bell.

From a height of 68 miles the unmanned and discarded ascent stage of Apollo 12's Lunar Module hurtled to a 3,750-mph crash on the moon. The 2½-ton craft's impact, 45 miles from the Ocean of Storms site where Conrad and Bean had just set up a new "moonquake detector," was equivalent to a ton of exploding TNT.

The object of the deliberate crash was to see what the instrument would report to earth, and the result astounded scientists. The moon rang like a bell! On earth, tremors from such an impact would have died out in a minute; on the moon they lasted almost an hour. Something about the moon's interior was new to science.

The moon is proving a wonderland of surprises. First came the unanticipated discoveries by the first moonmen, Apollo 11's Armstrong and Aldrin. Now Apollo 12 is adding more as its moon instruments report, and as experts examine its rich new haul of moon rocks—about double Apollo 11's booty of 47 pounds.

And that fulfills just what the most optimistic scientists had hoped—to find the moon so unlike the earth that our lunar explorers' finds could not have been foreseen. For its surprises, especially, promise the best chance of solving such mysteries as how the moon, earth, and solar system began.

Pieces of the moon tell their secrets. As this was written, detailed findings of the 142 investigators studying Apollo 11's moon rocks were about to be made public in a January conference at Houston. By agreement with NASA, the scientists were to keep mum until then. But NASA's own Preliminary Examination team, which studied the moon rocks intensively at Houston so that the right ones would go to the right scientists, had already announced a variety of striking discoveries:

Even the first, cursory inspection of Apollo 11's lunar-soil samples brought a surprise. Much of the looser soil consisted of tiny balls of glass, ranging up to a millimeter (about 1/25 inch) in size, and from "lemon-drop" yellow to deep reddish-brown in color. Acting like ball bearings, these unanticipated "moon beads" clearly accounted for the slippery footing Armstrong had reported in walking on the moon. And Apollo 12's astronauts, landing on the left side of the moon's face instead of the right, found them there, too.

Glistening in sunlight like light-reflecting glass beads in a highway sign, the "moon beads" excited scientists because they showed something unforeseen was happening on the moon. While theories varied, one held that impacts of meteorites melted silica-rich lunar soil to glass. A molten blob, thrown up and falling back in a vacuum, would be transformed by surface tension into a perfect sphere before it hit the ground.

Moon samples, like the astronauts themselves, underwent a three-week quarantine before release to the outside world. Tests showed they contained no living or-

Astounding age is most surprising property of these crystalline Apollo 11 moon rocks.

Moon Landings

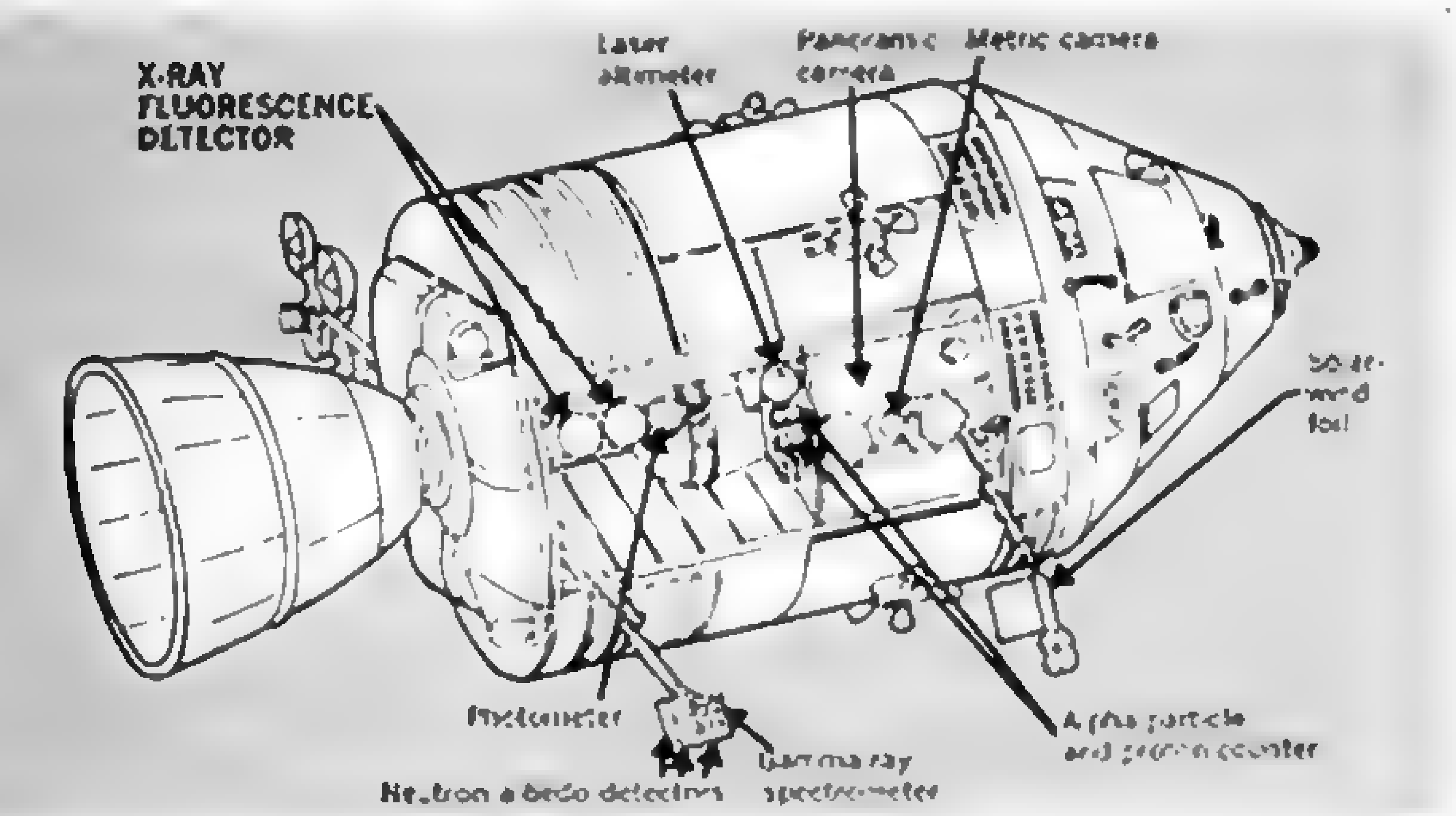
"Moon beads" of glass, magnified here more than 100 times, were unanticipated discovery by Apollo 11 on lunar surface. Apollo 12 found them, too. They explain slippery footing reported by the astronauts, who, in effect, were walking on ball bearings.

ganisms, nor even fossils, and exposure to moon soil had no ill effects on people, animals, or plants. That was no surprise. The real upset was that lunar material did have an effect—a beneficial one!—on plants like lettuce, tobacco, beans, and tomatoes. For example, tobacco had greener leaves, and lettuce seeds germinated better, in soil sprinkled with Apollo 11 moon dust. At this writing, biologists were still mystified, and could only conjecture that "trace elements" might have something to do with it.

Drops of "solder"—from a solar flare-up? Mysterious glazed spots resembling splashes of molten solder were found on the moon's surface both by Apollo 11 and 12 and pictured close-up with a "walking-stick" stereo camera. Some thought the glinting spangles, like moon beads, were spatterings of glass by meteorites. But the odd fact that they were invariably at the bottom of a small pit or crater led Cornell astronomer Thomas Gold to propose a more dramatic explanation:

A giant solar flare lasting 10 to 100 seconds, and packing perhaps 100 times the normal solar radiation, Dr. Gold suggested, melted the tips of rocks and of soil hummocks to form the glazed spots. Collision of a comet or

Plants grown in soil sprinkled with lunar dust, like sorghum and tobacco above, surprisingly thrived better than in plain earth.



To map moon's minerals from lunar orbit, this new gear for Apollo Command and Service Module would include remote sensors such as a detector for rocks' fluorescence under solar X rays.

asteroid with the sun might have triggered the flare. Its heat would have been trapped most effectively at the bottom of pits, where the drops of "solder" were found. Since they have survived incessant bombardment by micrometeorites, he concluded, this event must have happened fairly recently—perhaps less than 30,000 years ago, in the time of Neanderthal man.

Why haven't signs of it been found on earth, then? If the heat pulse were largely of ultraviolet radiation, as Dr. Gold surmises, our atmosphere would have shielded the earth from it—but the airless moon would have borne the full brunt.

Unearthly rocks. Surprises continued as analysts got down to work on the composition of Apollo 11's lunar rocks. Principal ingredients proved to be two silicate minerals, pyroxene and feldspar, and the titanium-bearing mineral ilmenite. Minor constituents included minerals known as olivine and cristobalite; almost certainly, native iron, and troilite (rare on earth except in meteorites); and a yellow crystalline mineral, not immediately identified.

What was unearthly was, first, the rocks' astonishing richness in titanium. They contained up to 12 percent of titanium oxide, compared to less than 10 percent for the richest terrestrial specimens. If Sea of Tranquillity soil were on an earthly beach, experts commented, you'd have a fine titanium mine.

Compared both to earth rocks and meteorites, the moon rocks proved unique, in their abundant content of high-melting-point elements—zirconium, chromium, and others besides titanium—and deficiency in low-melting-point ones like sodium, potassium, and lead. That made it look as if they were formed from a different molten magma, or by a different natural process, than any rocks we have known before. Seeking to learn how they came into being would be an intriguing quest.

Apollo 11's moon rocks, it proves, lack any gold, silver, or platinum—and, of more practical importance on the moon, any hydrated minerals that could be "mined" for water. There has been no water on the lunar surface at Tranquillity Base, geologists conclude, in the 20 to 160 million years that the rocks have lain there (a period estimated from isotopes produced by cosmic rays). But Apollo 12 shows how different even another "mare" area of the moon may be:

Almost all of Apollo 12's rocks are "igneous"—formed from molten lava, and still in their original crystalline form. This is a dramatic contrast to the Apollo 11 site, where both igneous rocks and another kind, called breccias, abounded. The breccias are cemented-together aggregates of lunar-soil particles—probably fused into solid rock by the shock of meteoric impacts. So you would expect to find them everywhere on the moon. Their scarcity in the Ocean of Storms is as surprising as would be a spot in the ocean floor where drills found no sediment.

Moreover, the first close look at Apollo 12's magnificent haul of rock specimens suggested their make-up would differ widely from Apollo 11's. By early estimates they might contain no more than an earthly two percent of titanium oxide; while perhaps 15 percent of olivine would contrast with that silicate mineral's scarcity in Apollo 11 samples. The 20th-century New World of the moon is proving a world of many faces.

Rocks' exciting age may disclose the past. Probably the moon rocks' most exciting surprise of all is their fabulous age. It may well make them the Rosetta Stone to bare the mysterious history of the moon, earth, and planets. This is the view of Prof. Robert Jastrow, the brilliant director of the Institute for Space Studies at NASA's Goddard Space Flight Center.

A comparatively rough-and-ready dating technique called the potassium-argon method, used in the preliminary examination of Apollo 11's igneous rocks, indicated that they crystallized three to four billion years ago. If the latter, they antedate any rocks known on earth. And future specimens from the lunar highlands, supposedly older than the "young" Sea of Tranquillity region, may take us back to the very beginning of the solar system—which, from studies of meteorites, is put at some 4½ billion years ago.

[More-precise dating methods at two laboratories have since pushed back the age of Apollo 11 rocks to a sensational *4½ billion years*—the age of the solar system itself—according to an unofficial advance "leak" of scientific investigators' later findings. The report was tacitly confirmed when Dr. Eugene M. Shoemaker, Caltech geologist and NASA consultant, predicted that this fantastic age would be the one accepted "when all the evidence is in." —*The Editors.*]

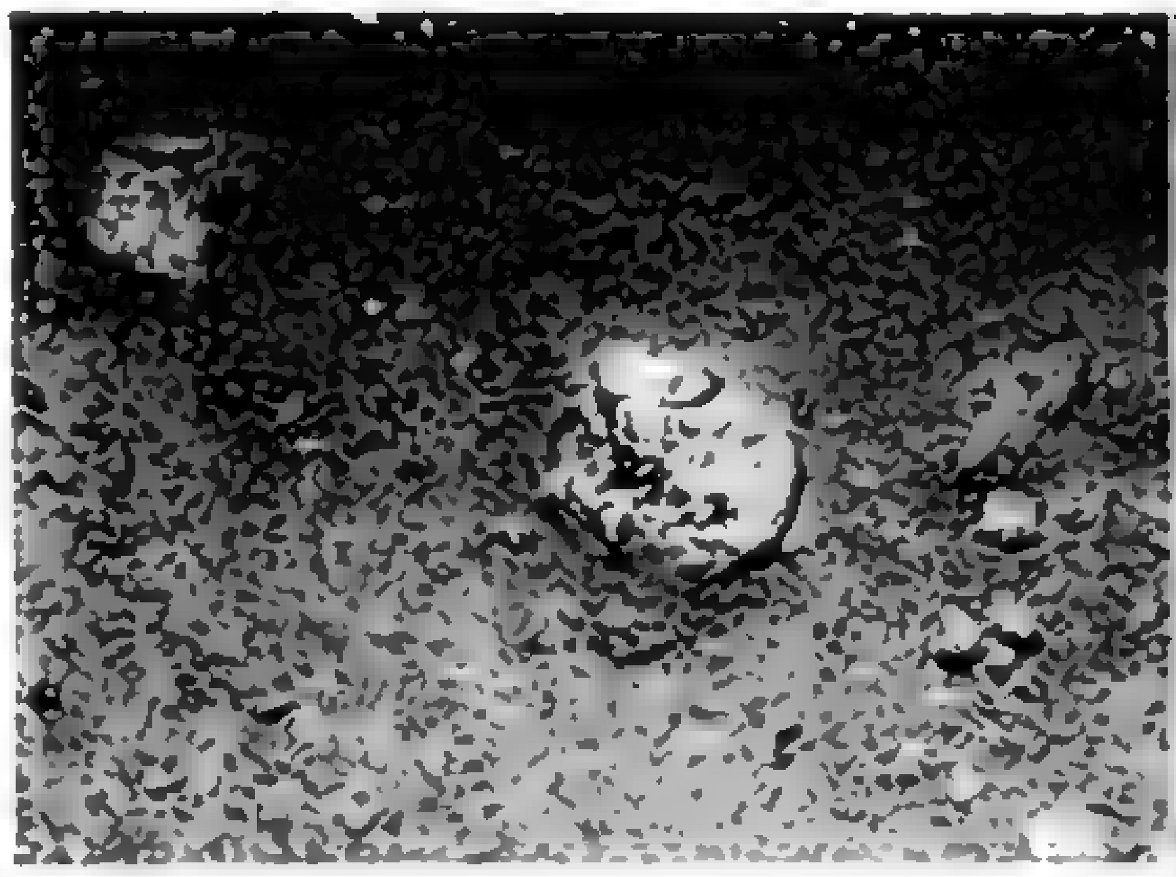
Listeners on earth followed first-hand the brilliant success of Apollo 12's moonmen in recovering parts of the Surveyor 3 spacecraft, to see what had happened to machinery exposed since 1967 to the moon's "weather." But a trophy perhaps as noteworthy was a photo of an imprint left by a bouncing Surveyor footpad. After 2½ years the one-foot-diameter impression remained as fresh as a newly minted coin, unscathed by any meteoric impact—proof positive of how long a target of known area could escape a hit. It was a statistic of no small interest to coming moon travelers and builders of moon shelters.

"Prospecting Apollos." Future explorers of lunar natural resources will need geologic maps to guide them

[*Continued on page 144*]

Surprising Facts We're Learning from the Moon Landings

(Continued from page 64)



Spangles resembling spilled solder, pictured above on lunar soil by the camera in view at right, have been called possibly a relic of a giant solar flare-up in the past.

"Walking-stick" camera, with built-in flash, was used by Apollos 11 and 12 to make extreme close-ups of lunar-soil details too fragile to bring back intact.

Toward that end, Apollo 11 moon rocks are being tested for luminescence under various kinds of radiation by Dr. Norman N. Greenman of Douglas Aircraft Corp., Santa Monica, Calif.

As prospectors know, some earthly minerals—like the tungsten ore scheelite and several uranium ores—fluoresce or glow in telltale colors under the "black light" of an ultraviolet lamp. Dr. Greenman already has shown that silicate minerals like the moon's can likewise be identified by their luminous response under X rays, protons, or ultraviolet light—all present in solar radiation striking the moon.

Once the fluorescent behavior of different lunar minerals is cataloged, a lunar-orbiting Apollo with remote sensors should be able to recognize and map these minerals anywhere on the moon. NASA is considering plans to equip an Apollo for that purpose—possibly in time for Apollo 16, the sixth lunar landing.

Moon instruments' surprises. Besides a laser reflector for earth-moon measurements, Apollo 11 left on the moon just one scientific lunar experiment—a solar-cell-powered "moonquake detector," or seismometer. In three weeks before it quit working, it transmitted puzzling reports. Experts found its squiggles hard to identify as meteoric impacts, landslides, or true quakes, because they were so unlike recordings on earth. Apollo 12, which set up a whole observatory of nuclear-powered instruments including a new seismometer, told why.

Key to the mystery was the Lunar Module ascent-stage crash, which provided an artificial impact of known magnitude. When the lunar tremors lasted 55 minutes, amazed observers saw that, to understand them, they would have to "throw the book away." Wild guesses were made and discarded before a reasonably likely explanation was tentatively proposed as to why the moon rang like a bell:

Echoes. The tremors, it was theorized, reverberated in a natural underground "echo chamber" of gravel and rocks, sandwiched between a roof and floor of lava beds. In such a formation on earth, liquids or gases in the interstices quickly "damp out" vibrations—but on the moon the voids are vacuums and the reverberations go on and on. Whether this theory ultimately prevails or is replaced by another, this much now seems to have been made clear.

From the prolonged after-effects of the ascent-stage crash, it's now concluded that the squiggles of Apollo 11's seismometer, spanning periods up to six or seven minutes, represented natural meteoric impacts; it no longer seems incredible, as it had before, that such tremors could go on so long. Apparently this instrument detected no true "moonquakes" at all. Whether the new one will do so remains to be seen; if not, evidence for a non-volcanic "cold moon" will be strengthened.

Apollo 12's lunar observatory already has furnished other surprises. Only after tests to make sure a magnetometer hadn't gone haywire did earth observers believe its readings. It showed a lunar-surface magnetic field of 30 gammas—only 1/1,000 of what swings a compass needle on earth, but five to 20 times what was expected on the moon.

This and other evidence will ultimately help tell what the moon's interior is like. Other instruments will detect any lunar atmosphere and ionosphere, and study "solar wind."

From the surprises of Apollo 11 and 12, one of the two outstanding conclusions is that we still have a lot to learn about the moon! The other is that what we do learn should be more intriguing than anyone, before the landings, had dared hope. ■

MARCH 1970 50 CENTS

Popular Science

THE *What's New* MAGAZINE

Now You Can Skim Over Hill and Bog, Snow and Water, in the Amazing New Air Cycle

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How Apollo 13 Will Probe the Moon's Interior
By WERNHER von BRAUN

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YOU CAN MAKE:
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- 4-Channel Stereo Conversion
- Your Best Fishing Rod
- Screw Threads in Wood
- A Unique Patio Table

How APOLLO 13 Will Probe the Moon's Interior

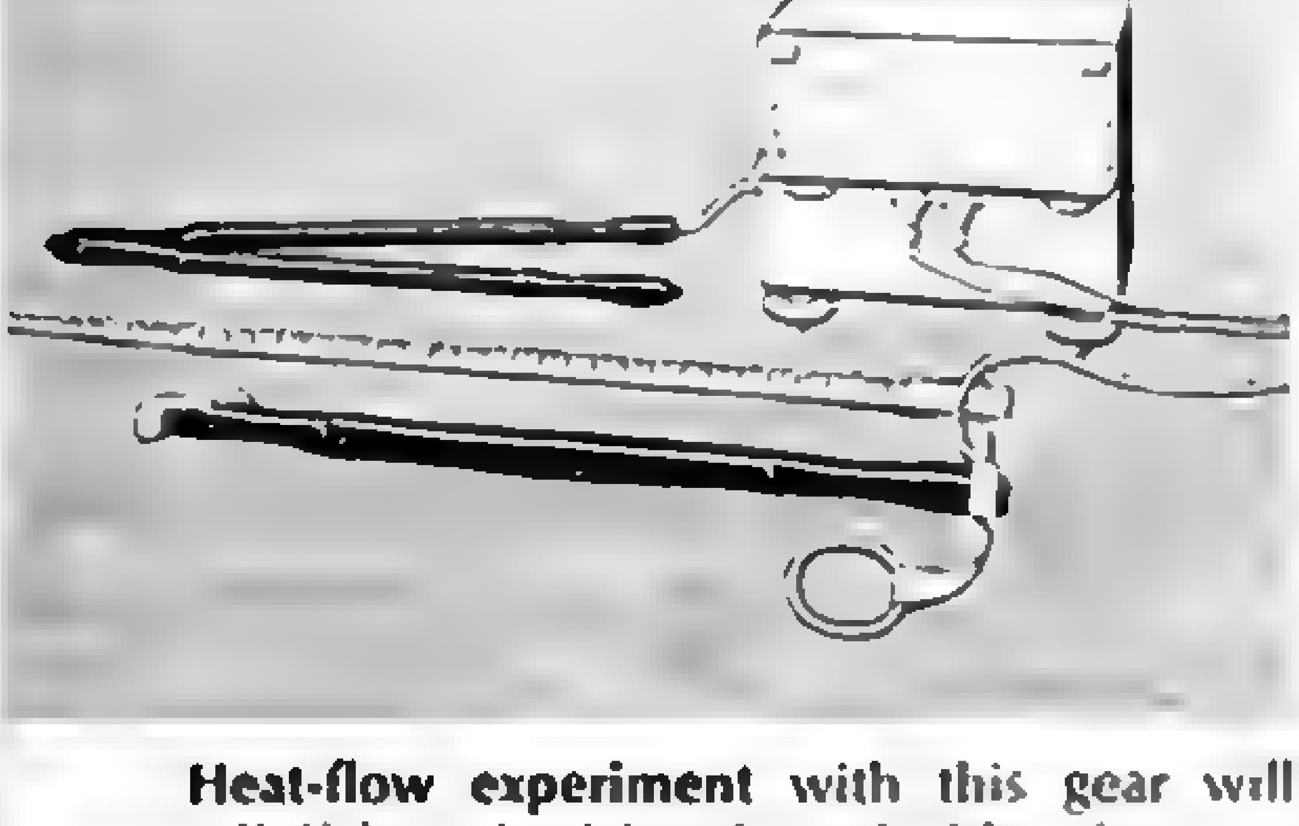
By
DR. WERNHER von BRAUN

From directing NASA's Marshall Space Flight Center at Huntsville, Ala., Dr. von Braun has just gone to Washington as one of NASA's deputy associate administrators. This is one of his frequent articles on space for PS

ILLUSTRATIONS BY RAY PIOCH

Crashing a Saturn rocket stage on the moon, and plumbing lunar depths with a key heat-flow experiment, will help our new lunar observatories bare the moon's secrets

Tapping moon's secrets with battery-powered core drill will be new Apollo 13 adventure. Drilling 10 feet down will get much deeper lunar samples than any yet. Then, one-inch-diameter holes will serve for new "heat-flow experiment" to help settle such disputed questions as whether moon has molten core like the earth's.



Heat-flow experiment with this gear will tell if heat is rising from inside of moon. Two-section probes measure temperature at different levels below the surface.

When Apollo 13 heads for our third manned lunar landing, next month, it will begin in earnest the intriguing task of exploring the moon's interior. The findings of Apollo 11 and 12, which hardly scratched the surface of the moon, have been so rich that scientists look forward eagerly to learning what is beneath. Coming experiments will tell.

With a new battery-powered core drill, Apollo 13 astronauts will bore two 10-foot-deep holes in the moon. That will bring up samples from far beyond the previous depth limit of about 40 inches—with Apollo 12's hand-coring tubes—where underground strata were getting more and more interesting. (One layer tentatively looked to scientists much like volcanic ash or pumice; and content of carbon, a prerequisite for possible life, was reported apparently increasing with depth.)

And, through a new "heat-flow experiment," the holes will prove an open sesame to what lies far deeper. On probes lowered into them, arrays of sensitive temperature-measuring thermocouples will tell whether heat is flowing outward from the inside of the moon to its surface. Subsurface heat conductivity will be measured, too, with the aid of small electric heaters in the probes. An underground temperature profile deduced from these tests will throw new light on whether the moon, like the earth, has deep, radioactive heat-generating layers and a molten core.

Biggest artificial meteor. An Apollo 13 "spectacular" will be the meteor-like crash on the moon of the great Saturn V rocket's whole top stage and instrument unit, totaling more than 15 tons' weight. Instead of being aimed past the moon as before, the rocket stage will be targeted at a point on the surface about 125 miles from Apollo 12's Ocean of Storms seismometer, which will register vibrations from the impact.

This will be a dramatic scale-up of the Apollo 12 experiment of crashing the empty 2½-ton ascent stage of its Lunar Module on the lunar surface. The astounding result of that crash: The moon rang like a bell for nearly an hour, indicating some strange and unearthly underground structure. Intended to probe this subsurface formation with stronger and longer-range seismic waves, the impact of the heavier and faster-speeding Saturn stage should really make the moon clang! For good measure, Apollo 13 will also crash its own Lunar Module ascent stage, some 42 miles from a new seismometer that it will have emplaced on the moon's surface.

The landing site. A lunar highland region named Fra Mauro (for a monk and cartographer of early times) has been tentatively selected as Apollo 13's prime landing site. Only about 110 miles east of where Apollo 12 touched down, it offers terrain of far different kind. Scientists picked it because of these characteristics:

- It is an "old" area where soil and rocks are untouched by volcanoes or the ancient lava flows believed to have formed the *mares* (such as Apollo 11's Sea of Tranquillity and Apollo 12's Ocean of Storms).
- Suspected in this area are *ejecta*, lunar-soil samples thrown from the depths by meteor impacts, from the Sea of Rains to the north.
- There is a high ridge of interest close to the landing site.
- There are some small bright impact craters that are believed to be of fairly recent origin.

Just in case a continuing study of Apollo 12 high-resolution photographs should reveal any unacceptable features of a Fra Mauro landing, a backup site has been earmarked near the Hyginus Rille, about 25 meridian degrees farther to the right on the moon's disk. It features a rather long linear "rille," or surface fracture, along a chain of small craterlets. Here, volcanic materials and "age dating" would be of primary scientific interest. But, as of this writing, nothing has come to light that would rule against the prime site, and so it looks as if Fra Mauro is "it."

Apollo 13 will be skippered by one

Continued

Spectacular Apollo 13 experiment will be 5,700-mph crash on moon of Saturn V rocket's 15-ton top stage. Seismometer in Ocean of Storms will register impact. This will be scale-up of 2½-ton Lunar Module ascent-stage crash that made moon ring like bell, and will explore the underground structure causing the unearthly effect with stronger and longer-range seismic waves.

of NASA's most experienced astronauts, Capt. James A. Lovell, Jr., USN. He was Frank Borman's sidekick in Gemini 7, which in 1965 set a still-uncontested world record of 14 days in orbit; and he was a member of the history-making Apollo 8 crew that orbited the moon on Christmas Eve, 1968. So it can truly be said that "Jim's been around." His travel companions in Apollo 13 will be two space rookies—research pilots Thomas K. Mattingly II, a Navy officer, and Fred W. Haise, Jr., a civilian.

The Apollo 13 backup crew will be made up of Cmdr. John W. Young, USN, skipper, and astronauts John L. Swigert, Jr., and Charles M. Duke.

Fra Mauro is the first Apollo landing site to be selected, not for smoothness and a minimum of hazards, but for scientific "paydirt." Setting the Lunar Module down in really nasty terrain will demand more time for hovering, so that its pilot—like a helicopter pilot—can select a safe landing spot among obstacles.

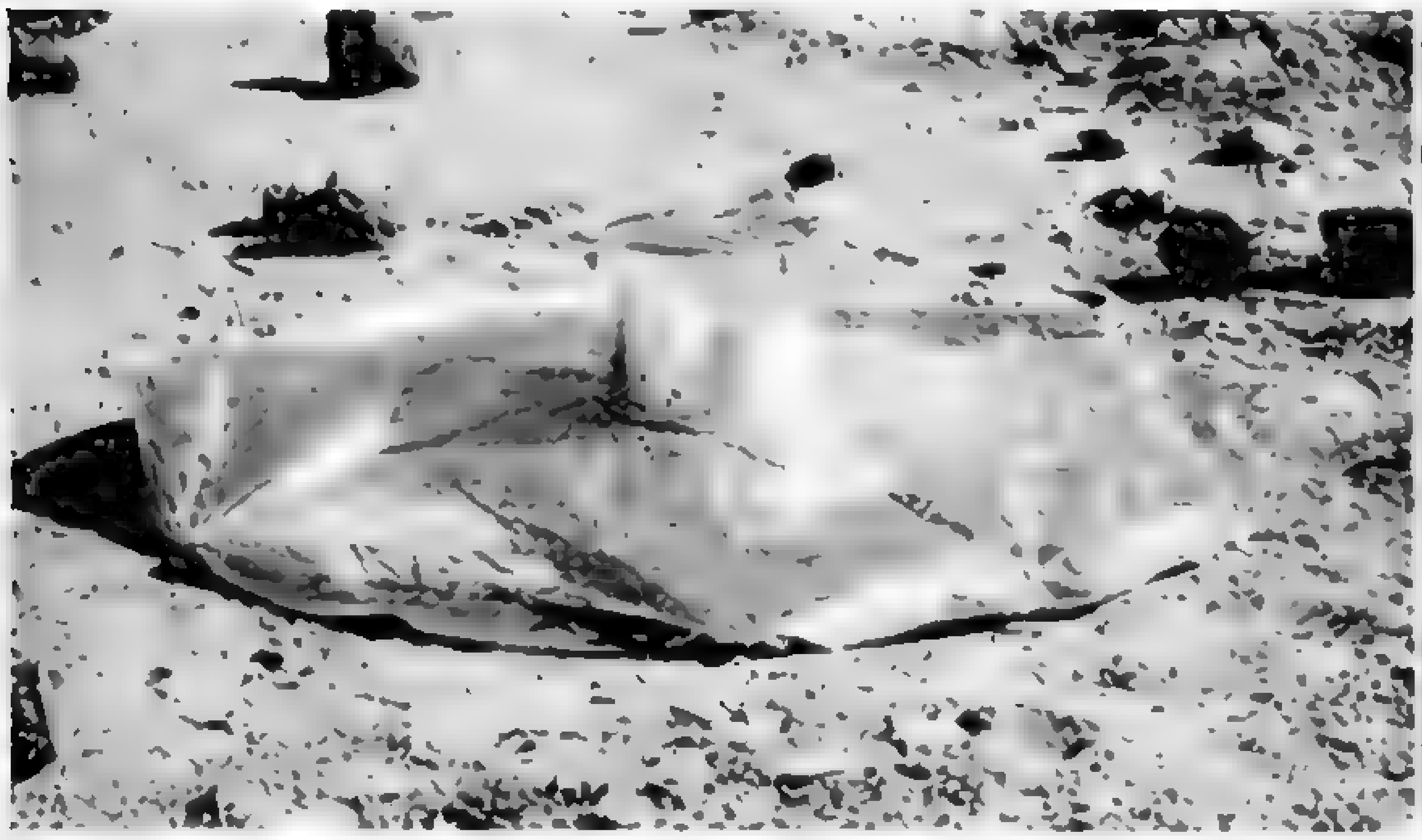
Had the Apollo 11 and 12 sites been much rougher than they were, or the crews less well trained, both Apollo 11 and 12 might have had to abort the landing attempt from a very low altitude—simply because they would have used up their small reserve of propellant for hovering, before the pilot could locate and commit himself to a spot smooth enough. As the Lunar Module (LM) rapidly descended through the last 100 feet of altitude, time to select an obstacle-free landing spot was awfully short. The target area came into view about 120 seconds before touchdown, but only the last 20 seconds or so revealed hazardous boulders and small rough-bottomed craters.

New strategy extends hover time. To enable the LM to hover longer, Apollo 13 will use, for the first time, a novel "delta-vee" strategy. In essence, it means that the Command and Service Module (CSM), instead of keeping to a lunar orbit nearly 70 statute miles high, will itself approach to within 10 miles of the moon's surface before the LM separates for a landing.

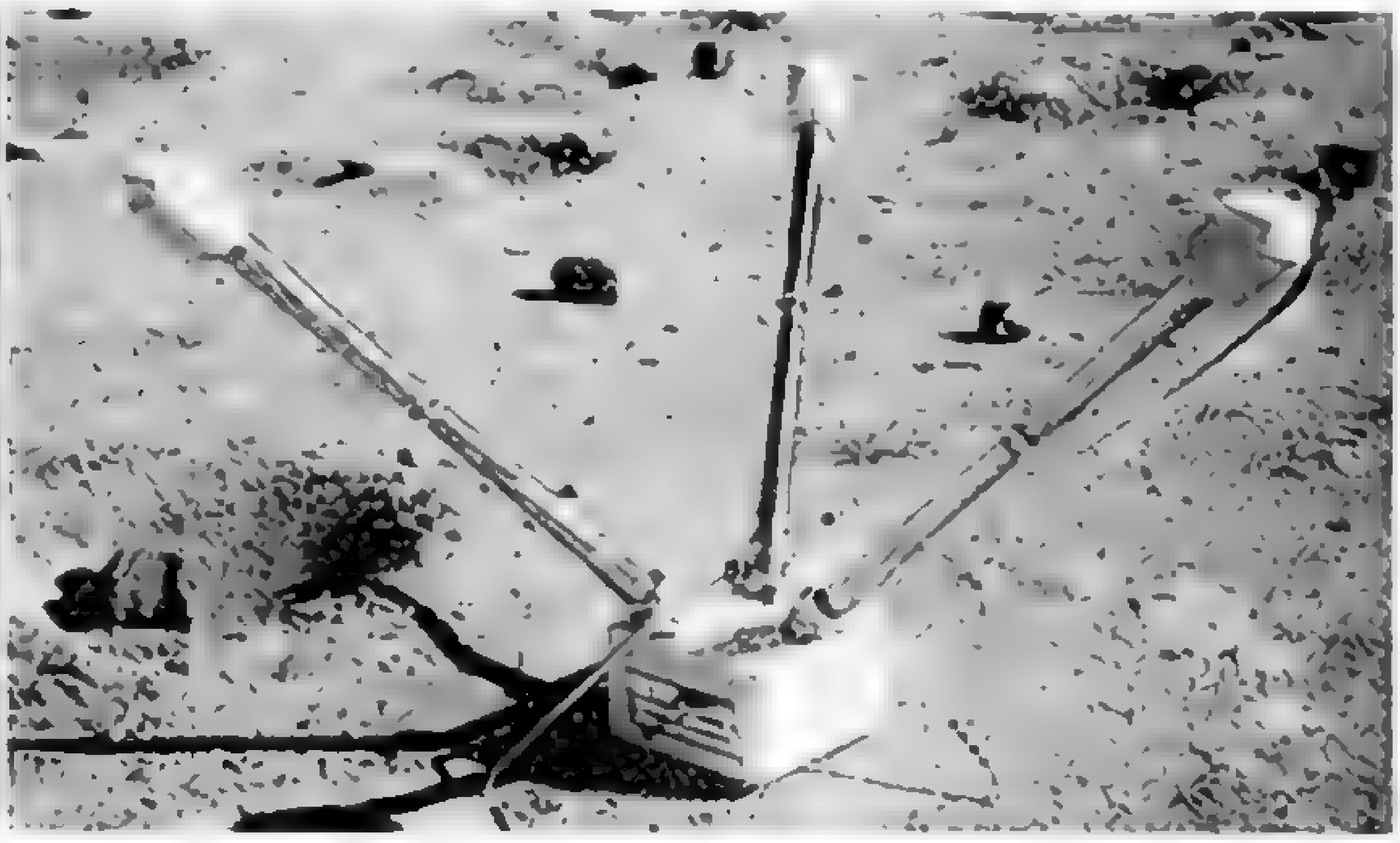
The velocity-change capability of

[*Continued on page 150*]

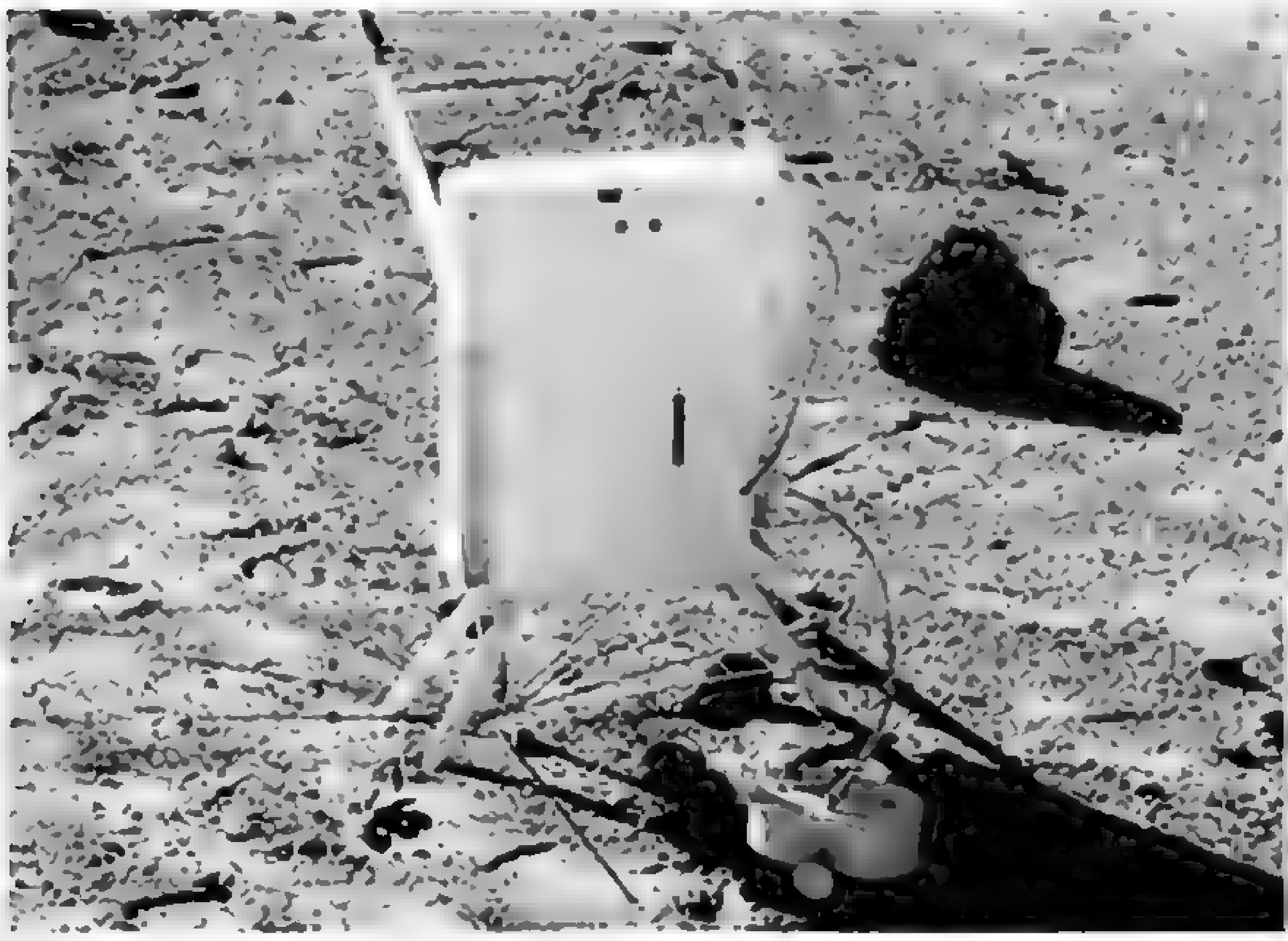
"Central station" holds nuclear-power supply for Apollo 13 moon-observing instruments. Atop it is radio antenna.



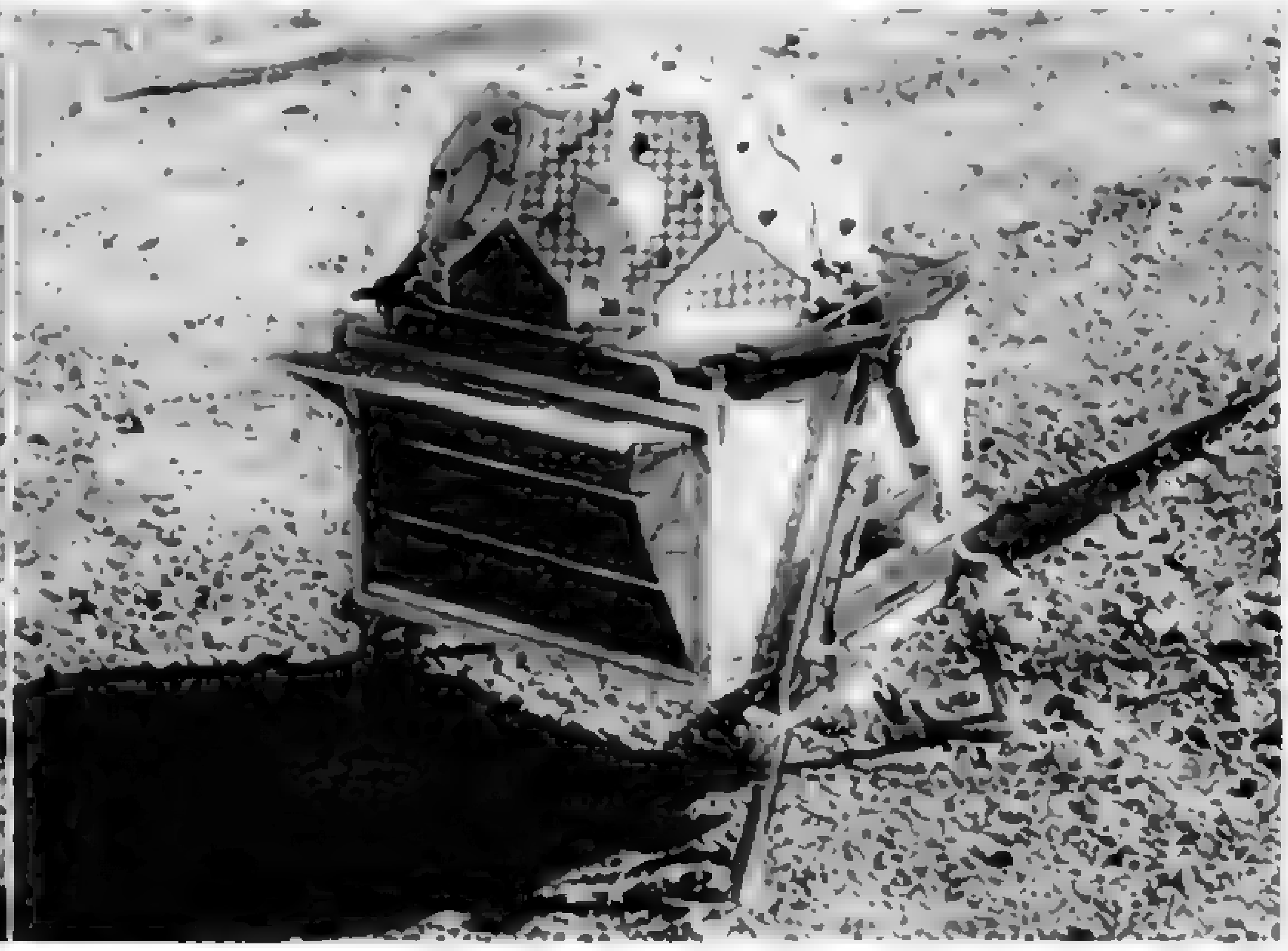
Lunar observatory to be emplaced by Apollo 13 includes drum-shaped seismometer, above, to detect quakes and meteoric impacts. "Thermal shroud" limits temperature fluctuations within



Magnetic field on moon is recorded by magnetometer, with three sensors at right angles to each other on three-foot booms. Similar Apollo 12 model found site more magnetic than expected.



Lunar-ionosphere detector will observe charged particles near moon. Lunar-atmosphere detector, built into pictured Apollo 12 version, will be separate unit in Apollo 13's instrument package.



Solar-wind spectrometer, to monitor stream of electrons, protons, and other particles bombarding the moon from the sun, completes Bendix-designed package of lunar instruments.

Probing the Moon's Interior

[Continued from page 58]

any rocket-powered stage or vehicle is called Δv, pronounced delta vee. For a given rocket stage, it increases with the amount of propellant carried by the stage. It is intimately concerned with the mechanics of a lunar landing—for which the forward velocity of the LM must be progressively reduced from moon-orbiting speed to zero at touchdown.

In Apollo 11 and 12, the LM descent engine did it all, in this fashion: The LM separated from the CSM in a circular lunar orbit of 69 statute miles' altitude. It fired its descent engine for a Descent Orbit Injection (DOI) maneuver, which put it in an elliptical 69-by-nine-mile orbit. At this orbit's lowest point, the LM fired its engine a second time for Powered Descent Initiation (PDI), to eliminate horizontal velocity in its final descent to the lunar surface.

In Apollo 13, by contrast, the Service Module engine will provide the DOI velocity change required to enter elliptical orbit. The LM descent-stage tanks thus will be still untapped at PDI. The LM propellant saved will be available at the end of powered descent for extra hovering time before touchdown.

After a few revolutions of the CSM through the 69-by-nine-mile ellipse, the Command Module pilot will fire up his Service Module engine again and climb back to his original 69-mile-high circular orbit. In this circular orbit, the LM will ultimately rendezvous with him again.

"Hybrid" trajectory helps. Aren't we "robbing Peter to pay Paul" by reducing the Δv reserve of the CSM to increase the LM's hover reserve? We are indeed—but we can afford to, because the Service Module now has a comfortable extra reserve that we can tap. This results from having ended for good, after Apollo 11, the "free-return" feature of the lunar-approach trajectory.

Apollo 8, 10, and 11 sailed to the moon along a trajectory that would have thrown the astronauts right back to earth, had the service propulsion system failed to fire up and brake their craft to capture in a lunar orbit. Effective with Apollo 12, this free-return feature was given up in favor of a so-called "hybrid" trajectory. This trajectory will not carry the spacecraft automatically around the moon and back to earth, in case of a service propulsion failure. However, the crew can still turn the craft around and fire up the LM descent engine to drive the CSM/LM home.

Approaching the moon in a hybrid trajectory rather than a free-return one has the advantage of reducing the Δv requirement of the service propulsion system. The fuel saved can now be used for the additional DOI maneuver by the CSM, which preserves valuable hover fuel for the LM.

Activities on the moon. Apollo 13 will spend about 35 hours on the moon. Two "moonwalks," again of three to four hours each, may take the two LM astronauts as far as ⅝ of a mile from the landing spot—more than twice the outward range of Apollo 12's excursions. (A roving vehicle extending the astronauts' radius of action to about 15 miles will await Apollo 17, still some time ahead.)

Once more, the astronauts will collect a wealth of lunar specimens. All they do will be thoroughly photographed, and everybody seems confident that this time the color TV—complete with zoom lens—will work.

The astronauts will leave behind them a new nuclear-powered lunar observatory. Besides the added heat-flow experiment, it will include all the instruments that Apollo 12 put on the moon before: a seismometer, a magnetometer, a lunar-ionosphere detector, and a solar-wind spectrometer. A nuclear generator, in which thermocouples turn heat from plutonium-238 into more than 60 watts of electricity, provides power for all the instruments throughout the lunar day and night.

Apollo 13's moon observatory is called ALSEP III, short for the third Apollo Lunar Surface Experiments Package. (Apollo 12's was ALSEP II; Apollo 11's, for the first manned landing, was a simpler version named EASEP for Early Apollo Scientific Experiments Package.)

"Bootstrap photography." Finally, while the Apollo 13 LM crew is on the moon, the orbiting CSM pilot will try to get the very best high-resolution photographs of sites earmarked for future landings—an Apollo procedure known as "bootstrap photography."

The targets accessible for this work are somewhat tied to the location of the landing site of the picture-taking mission. For instance, if Apollo 13 proceeds as planned to the Fra Mauro site, its bootstrap photography will concentrate on the crater Censorinus (prime site for Apollo 15) and Davy Rille (alternate site for Apollo 18). Should Apollo 13 be diverted to its own alternate, Hyginus Rille, its bootstrap target would be the crater Copernicus, the prime site for Apollo 18.

Thus will continue the useful bootstrap photography begun with Apollo 8. For on the moon, just as on the earth, it helps to know what to expect at your destination. PS

Enjoy Surround Sound Now

[Continued from page 148]

ordinarily unnecessary because there are many excellent stereo amplifiers and receivers on the market with tape-head inputs all ready to go.)

Another solution to the electronics problem, if you are starting from scratch, is to buy all four channels of amplification in one unit. The Scott Quadrant listed in our box was the first of these on the market. It has a number of control conveniences designed expressly for four-channel stereo, including a master volume control for all four channels.

The amateur electronics buff will think of a number of other ways to get the four channels. For example, if he has one stereo amplifier without tape-head electronics, he can build a four-channel preamplifier/equalizer, a small unit that will probably fit into the tape machine. Then he buys another amplifier like the one he has. The four signals come out of the tape machine to be fed to the two stereo amplifiers.

Or maybe he has a high-grade tape machine with excellent electronics built in. He can build and install a duplicate of the two-channel preamplifier in his machine.

Those four speakers? Experience so far indicates that the two rear speakers can be different from the front ones, but they should be comparable in quality. I got excellent results with two AR-2x's in front and two AR-4x's in back.

Set-up and operation. With two separate stereo amplifiers, you have an easy way to balance front and rear sounds if one amplifier carries the two front channels and the other the rear two. And, this arrangement preserves complete compatibility with standard two-channel tapes. The only adjustment you must make to play standard two-channel tape is to turn off the rear amplifier.

The main problem in operating the system is getting the volume level in the front speakers equal to that in the rear. With identical amplifiers and speakers you will probably come quite close when the volume controls on the two amplifiers are at the same setting.

A number of the tapes that have been issued include tones or voice announcements at the beginning to help with level setting. You can do quite a good job with these by matching the apparent volume in the front speakers with that in the rear. The Scott Quadrant amplifier has the refinement of a meter on each channel that shows the output level. That's fine, but remember it will tell you how the *sounds* are balanced only if all four speakers are alike. PS

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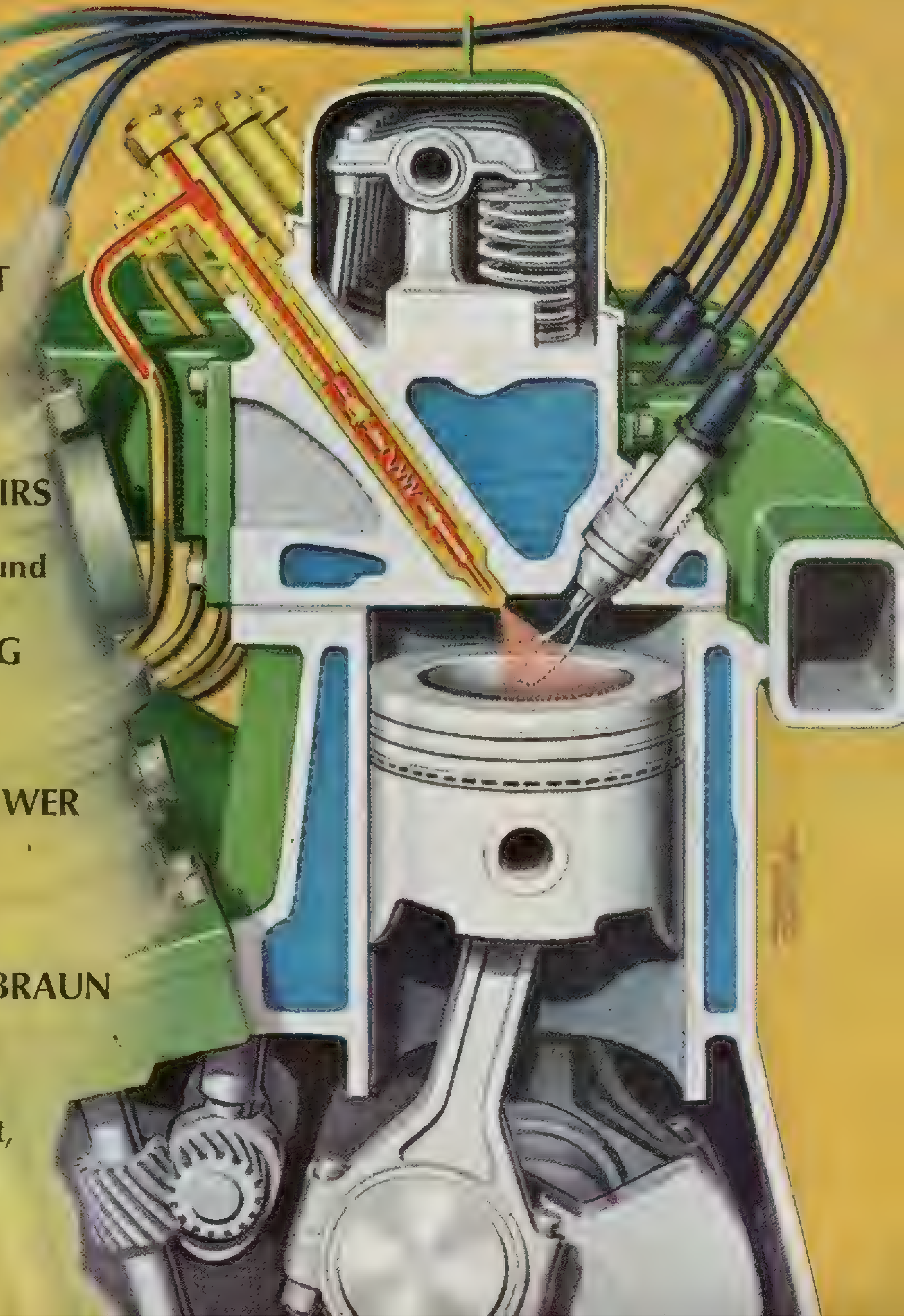
Popular Science

THE What's New MAGAZINE

Ford's New

SMOG-FREE ENGINE

- 10% more gas mileage
- 25% more power



ALL IN THIS ISSUE

Giant Full-Color
U.S. TRAVEL MAP
of Exciting Events
You'll Want to See

FLY IN—CAMP OUT
New Way to Stretch
Your Vacation

How You Can Beat
the High Cost of
AUTO-BODY REPAIRS

The Case for Year-Round
**CENTRAL
AIR CONDITIONING**
in Your Home

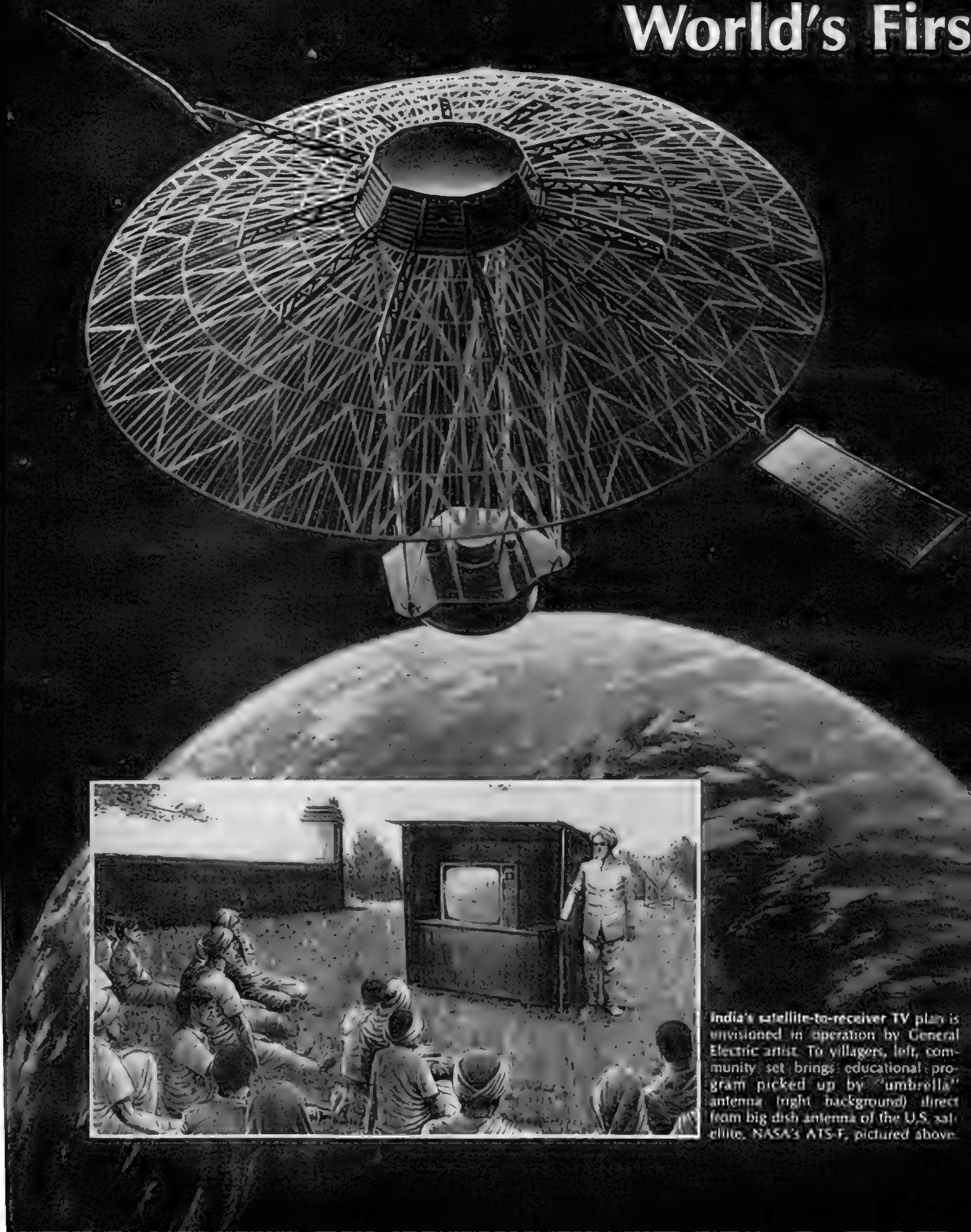
Quick Fixes for
YOUR POWER MOWER
Problems

World's First
TV Broadcast Satellite
By WERNHER von BRAUN

...plus 22 other
exciting new features,
the What's New Digest,
and 10 popular
every-month features

With a novel U.S. relay station to be orbited 22,300 miles high, India will pioneer in "skycasting" direct to TV sets on earth

World's Firs



India's satellite-to-receiver TV plan is envisioned in operation by General Electric artist. To villagers, left, community set brings educational program picked up by "umbrella" antenna (right background) direct from big dish antenna of the U.S. satellite, NASA's ATS-F, pictured above.

By DR. WERNHER von BRAUN
NASA Deputy Associate Administrator

TV Broadcast Satellite

"Father" of mighty Saturn V moon rocket, Dr. von Braun now heads NASA's plan-making at Washington. Earlier, he directed Marshall Space Flight Center at Huntsville. Dr. von Braun is PS Consulting Editor on Space.

For the first time, TV programs will be broadcast from a satellite direct to viewers' receiving sets, through an agreement concluded at Washington on Sept. 18, 1969, by the United States and India. Under it, 20 million people living in 5,000 villages of India will benefit from a dramatic educational-TV project—and much of the world, the U.S. included, will be the gainer from the technological advances involved in carrying it out.

A milestone in the rapidly growing role of communications satellites, the U.S.-India pact signals the start of a trail-blazing experiment to fight ignorance and hunger in developing and overpopulated countries—particularly in Asia and Latin America, and possibly also in Africa.

U.S. to put up the satellite

The agreement calls for NASA to provide and orbit the world's first TV broadcast satellite, in a stationary or synchronous 22,300-mile-high orbit over the Indian Ocean. Flying at this altitude above the equator from west to east, the satellite will have a period of revolution of exactly 24 hours, just matching the earth's period of rotation. Thus the satellite will hang at a fixed point in the Indian sky, day and night, rain or shine.

The TV satellite will be one of NASA's Applications Technology Satellites, the ATS-F, now expected to be launched in early 1973. It will have a solar-powered 80-watt transmitter; a 30-foot-wide parabolic antenna aimed at the Indian subcontinent; and a suitable receiver to intercept a TV program beamed up to it from a central Indian ground transmitting station. The satellite will rebroadcast the program back to earth through a searchlight-type beam covering most of India.

The central transmitting station will be at Ahmedabad, about 250 miles north of Bombay. The government of India, which will establish this station, will also furnish 5,000 "village receivers." These community TV sets will be distributed among 5,000 villages in four Hindi-speaking states—Rajasthan, Bihar, Madhya Pradesh, and Uttar Pradesh. The Indian government plans to buy these receivers from local sources, thus combining the educational merits of the program with a healthy shot in the arm for its domestic electronics industry.

The U.S.-India accord involves no exchange of money; the parties simply commit themselves to furnish their respective parts of the satellite TV system. The United States will stay completely out of the act of preparing the TV programs.

By Indian government plans, educational programs will provide what the people in those 5,000 villages need most. There will be "reading, 'riting, 'rithmetic" for the kids; there will be advice to farmers on how to plant, fertilize, and irrigate crops; and there will be counsel on hygiene and family planning, often eagerly sought. The programs are expected to be popular hits—for, as a United Nations official has observed, "The word 'education' in India is as holy as the cow."

Project challenges engineers

From an engineering standpoint, both the ATS-F satellite and the ground equipment pose many challenges, some unique.

The satellite will weigh about 1,600 pounds and will have a transmitter about three times as powerful as those in present communications satellites. The continuous fine-pointing of its large 30-foot dish antenna raises a number of unprecedented problems.

The antenna must maintain the angular direction of its searchlight beam with an accuracy of 1/10 of a degree. Much attention must be devoted to the antenna's power feed system to avoid undesirable "side lobes" in the radiation pattern, through which some of the emitted energy would spill over to countries bordering India. Fine-pointing also requires exact station-keeping of the satellite in its orbital position; here, too, accuracy specifications are tighter than for any synchronous satellite launched before.

The ground transmitter at Ahmedabad is relatively straightforward, but producing the 5,000 community receivers at acceptable cost offers more of a problem.

Beginning with Early Bird in 1965, all commercial communications satellites have relayed telephone calls, still pictures, and TV shows from an overseas transmitter to an elaborate multimillion-dollar receiving station capable of handling very weak signals. Processed and amplified, the TV signals then travel across country over microwave links, to be rebroadcast by local TV stations for nationwide reception.

India's key problem is that, except for one experimental government station in the area of the capital city of New Delhi, TV stations are nonexistent. Establishing them would be expensive and unattractive, because only a small segment of the population could afford private TV sets. Community sets, directly receiving programs beamed from a satellite in the sky, are indeed the only answer—if they can be built cheaply enough.

The "business end" of such a community set is not much different from your home TV set. It will have a 23-inch screen, black-and-white or color—and, with tubes and supporting electronics, can be had for something like $500. But, to receive a TV broadcast from a satellite, the "input end" of the set must be quite different from the kind for your own receiver.

Set needs "umbrella" antenna

To intercept a maximum of the energy beamed down by the satellite, the standard rake-shaped TV antenna must be replaced by an "umbrella" antenna of at least 10-foot diameter—mounted so as to be aimed precisely at the invisible transmitter hovering in the sky, more than 20,000 miles away. The weak signal picked up by this umbrella must pass through a preamplifier to a special converter, which changes the satellite transmission (UHF) into a signal suitable for reception on standard (VHF) television channels.

Today the combination of umbrella antenna, preamplifier, and converter still costs well over $1,000. Together with the $500 TV set itself, this would

run the cost of a village receiver to something like $1,500; and of the whole 5,000 sets to $7½ million. But mass-production techniques can be expected to reduce the total cost of a community set to $500, saving the project a tidy $5 million.

Considering the much higher cost of the satellite itself, a difference of $1,000 in a community receiver's cost might not seem too important at first glance. But the U.S.-India project is viewed by both parties as an experiment that, if successful, may pave the way for a vast extension of the system of broadcasting TV programs from a satellite.

Bigger plans ahead

India has a total of 530 million people, the great majority of them scattered in no less than 534,000 villages. Eventually, India looks forward to a satellite-TV network covering all this territory, and capable of handling TV shows narrated in any of its 120 different languages and dialects. The importance of cheap ground sets for such an extended project is obvious.

Only a relative few of India's villages have rural electric power for the receiver sets. While a few more can bring it in from nearby lines, most village sets will have to be powered by generators driven by lawn-mower-type gasoline engines (hopefully noiseless). It is not unlikely, however, that in many locations a man pedaling away on a stationary bicycle will take the place of the little gasoline engine, to generate the 100 watts or so required to power the receiver station. That primitive way to obtain electricity will make a curious contrast with the advanced technology represented by the ultramodern TV satellite system.

Brazil, too, is interested in using an ATS satellite to broadcast educational TV. Its plan, under U.S. study, would place the receiving sets in schools—first, several hundred schools in the state of Rio Grande do Norte, and ultimately as many as 150,000 throughout the country. During evening hours, the system could serve for adult education. A ground transmitting station at Natal on the Atlantic coast is envisioned for the Brazilian satellite-TV project.

In our interdependent world, the U.S. has much to gain from improved living conditions in developing countries. And TV broadcast satellites may have more direct benefits for us, nearer home. Our own state of Alaska is one of many world areas where they appear to have promise.

For most of the U.S., already served by the vast network of local TV stations and microwave links that brings you TV now, direct satellite-to-viewer TV broadcasting looks more distant and controversial. Nevertheless, it has been getting serious study by leading electronics firms, as evidenced by reports to NASA of GE and RCA progress in designing suitable equipment. And a recent report by John L. Hult, a Rand Corp. researcher, champions the feasibility of receiving TV direct from a high-power broadcast satellite—wherever you may go—with a portable antenna small and flat enough to be installed in your car's roof.

Currently discussed as a U.S. possibility, too, is another innovation in communications satellites—a domestic system of "distribution" satellites that might challenge the present microwave land systems as a means of linking the country's network of local TV stations.

A look into the future

All in all, you are bound to benefit from communications satellites in your lifetime. Arthur C. Clarke, the perceptive British writer and originator of the idea of synchronous communications satellites, sees this prospect ahead:

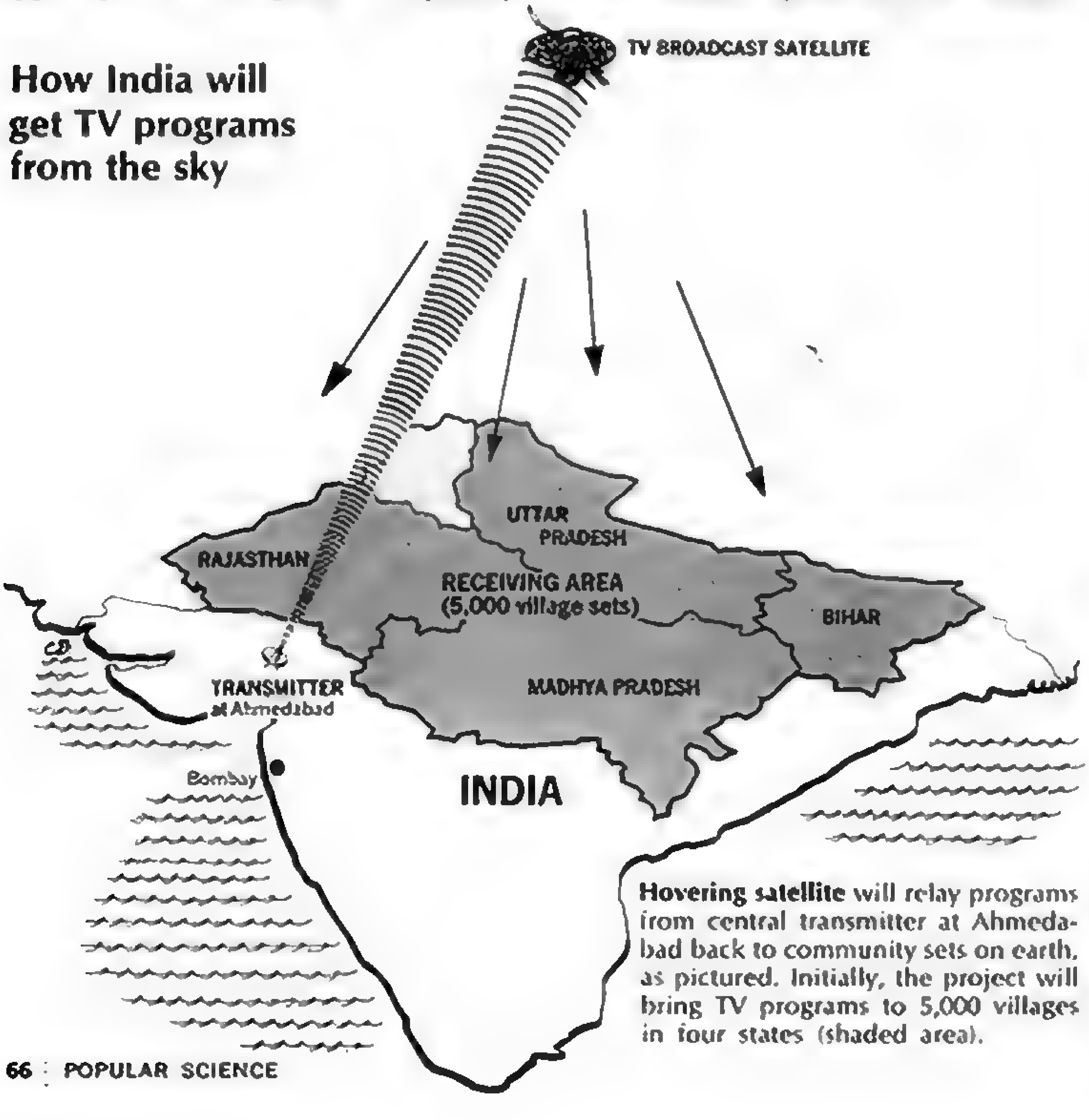
Imagine a console in your office, he says, combining the features of a Touch-Tone (pushbutton) telephone, a television set, a Xerox machine, and a small electronic computer. Tuned in to a system of synchronous satellites, this console will bring the accumulated knowledge of the world to your fingertips.

By punching a few digits, you can verify a check, get the data on some historical event, or hear an illustrated lecture on any subject you wish. Or you can hold an electronic conference with any group of people scattered all over the world, seeing each other as you talk. And the console will even provide you with a document to seal an agreement.

Once we all have such a console, Clarke foresees, we'll have little need for business trips, and will limit our traveling to the pursuit of fun. A man will be able to run his business just as effectively from a ranch in Wyoming as from an office in New York City or Chicago.

If Clarke is right, better communication via satellite could stem or reverse America's trend toward the big city—and alleviate problems like urban decay, smog, polluted rivers, clogged traffic, and crowded airports. These effects, of course, would be long-term. But, just as the telephone and airliner helped make the U.S. a great nation, so the communications satellite may yet turn out to be the greatest thing the space program ever contributed to this country.

How India will get TV programs from the sky



Hovering satellite will relay programs from central transmitter at Ahmedabad back to community sets on earth, as pictured. Initially, the project will bring TV programs to 5,000 villages in four states (shaded area).

JULY 1970 50 CENTS

Popular Science

THE *What's New* MAGAZINE

How You Can OWN AND FLY Your Own Personal Whirlybird

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The Spaceplane
That Can Put You in Orbit
By WERNHER von BRAUN

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Are Going to
WORK FOR YOU

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10,000-MILE TEST DRIVE
of the GREMLIN
First U.S. Mini-Compact

I MAKE
ay Canoe
a Table Saw
hat Burps Your Battery
-Way Patio Furniture
-Light Experiments

more
reports,
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regular features

The Spaceplane That Can Put YOU in Orbit

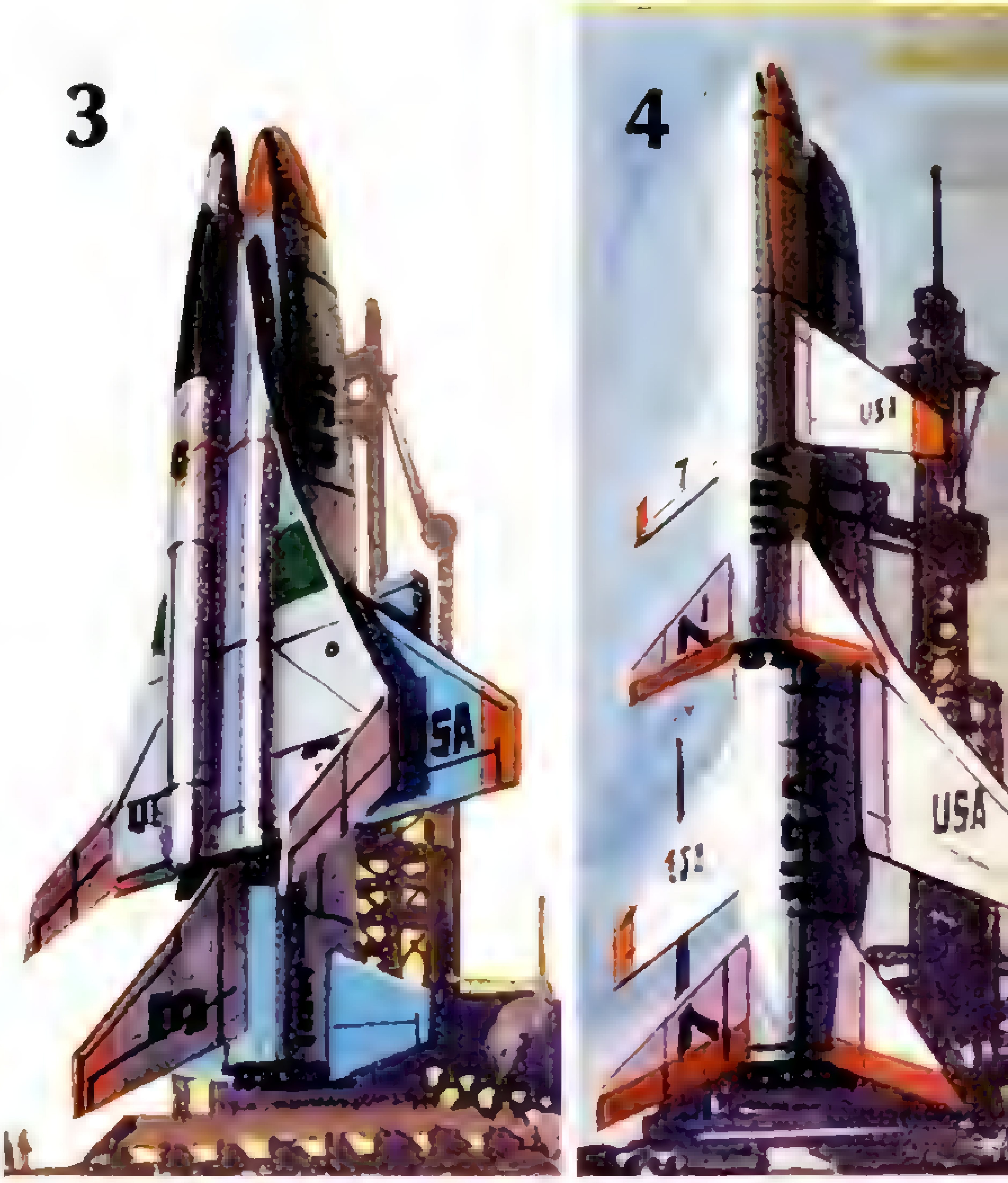
You won't need a "contour couch" or an astronaut's training to ride comfortably into space in NASA's shuttle craft (late-1970s model)

By DR. WERNHER von BRAUN
NASA Deputy Associate Administrator
PS Consulting Editor on Space

ILLUSTRATIONS BY BOB McCALL

Four Space-Shuttle Concepts

Here are examples of tentative designs for a space shuttle, made public by members of the four industrial teams competing in the project: 1. McDonnell Douglas/Martin Marietta. 2. Boeing/Lockheed. 3. North American Rockwell/General Dynamics. 4. Grumman Aerospace. Each of the pictured space-shuttle versions is a composite craft consisting of two stages, a booster and an orbiter, and is launched vertically like a space rocket, as shown. Its two stages separate in space, and both return to earth for re-use.



Toward the end of the Seventies you will no longer have to go through grueling years of astronaut training if you want to go into orbit. A reusable space shuttle will take you up there in the comfort of an airliner.

Just as in a commercial jet, professional flying will be required only in the cockpit. In the rear, it will be "coffee, tea, or milk," but you may have to share the accommodations with some high-priority cargo or laboratory equipment.

Shuttle to be reusable. Unlike the expendable launch vehicles and the non-reusable spacecraft of the Mercury, Gemini, and Apollo brand, the space shuttle of the late Seventies will return to the launching site and, after careful checkout, refurbishment, and refueling, can be used over and over again, hopefully a hundred times or more. This will permit significant reductions in the cost of future space operations: Today it still costs between $500 and $1,000 to orbit one pound of payload. With the shuttle, costs are expected to drop to about $50 a pound.

These savings in hauling costs are by no means the only advantages offered by the shuttle. The craft's benign flight environment—moderate accelerations, low noise levels, shirt-sleeve operations throughout the entire flight—will enable scientists and technicians without aviation training to ride it. Moreover, it will permit, at least in some flight missions, the use of normal laboratory equipment and instrumentation in space. This is of great significance; while the sophisticated equipment of some of our present unmanned spacecraft costs as much as $10,000 to $30,000 per pound, some commercial laboratory equipment and instrumentation can be had for about one percent of that cost.

It would be ideal, of course, if we could build a single-

Artist's conception of space shuttles in action shows passenger shuttle about to dock at future space base, left, orbiting earth (top

stage-to-orbit shuttle which, without shedding any boost rockets or tanks, could fly directly up to orbit and return in one piece to the takeoff site for another flight. Although we may well know how to build such a vehicle some day, most studies unfortunately show that with the present state of propulsion and structural technology this objective would be just a shade too ambitious. A single-stage-to-orbit vehicle, by definition, must be capable of carrying its entire dry weight, plus return fuel, crew, passengers, and cargo into orbit; and its own dry weight makes up

left). Utility shuttle, right, retrieves out-of-order earth satellite for repair in orbit. Spacemen with self-propulsion gear aid operations.

the major part of this load. A minor overshoot in its projected structural weight, or a loss of as little as one percent in rocket-engine performance, could therefore wash out the entire payload! Technological advances will undoubtedly improve the successful chances for such a single-stage shuttle design, but at the present time, few aerospace contractors are willing to take the gamble.

The shuttle concept NASA considers most attractive at this time is a two-stage, vertical-takeoff vehicle, with

[*Continued on page 104*]

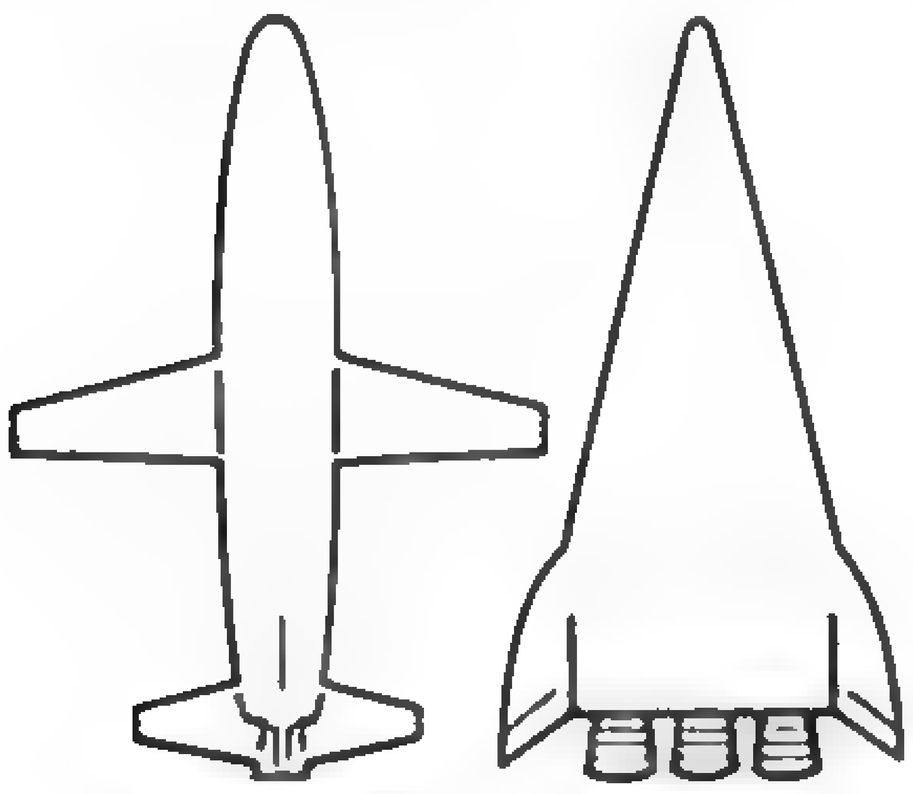
Spaceplane to Put You in Orbit

[Continued from page 39]

both stages fully reusable and designed for an aircraft-type, horizontal landing. According to the present "wish list," the orbiting part of the shuttle should accommodate a payload weighing between 25,000 and 50,000 pounds, which would fit into a cargo-bay volume of about 10,000 cubic feet. The takeoff weight of such a vehicle could be on the order of 3½ million pounds.

Two different shuttle concepts are presently under detailed study. They are similar in terms of size, performance, and shape of the earth-to-orbit flight path, and in both configurations the booster is separated from the orbiting element at an altitude of about 200,000 feet and a speed of about 6,000 miles per hour (or about nine times the speed of sound). At this point, the orbiter lights its own rocket engines and continues until it reaches orbital speed and altitude, while the booster descends unpowered to lower altitudes, with aerodynamic drag continuously reducing its speed. Once down to 30,000-foot altitude and subsonic speeds, the booster starts its air-breathing turbojet engines, turns around, and flies the 250 miles or so back to the launch site where it makes an airplane-type landing.

Two kinds of orbiters. The basic



difference between the two concepts lies in the design philosophy for the orbiter. The orbiter in one concept has fixed, straight wings; in the other concept it is delta-shaped. (See illustration above.)

Let's look at the straight-wing orbiter first. This concept has been suggested and studied in great detail by Dr. Maxime Faget of the Manned Spacecraft Center in Houston, who fathered the whole breed of "blunt-nose" Mercury, Gemini, and Apollo space capsules. Faget's straight-wing orbiter would reenter the atmosphere at an extremely high "angle of attack" —with the nose no less than 60 degrees above the flight path. This is the same angle of attack at which the Apollo Command Module reenters the atmosphere when returning from the moon.

We might, indeed, consider the underside of the straight-wing orbiter as a cross cut out of the Apollo heat shield, and thus readily relate its aerodynamic heating to that of an Apollo capsule returning from orbit. As it also utilizes the "blunt-end-forward" principle, the heating of the orbiter's underbelly is indeed minimized while its upper surface areas, being exposed to a detached airflow only, receive even less aerodynamic heating. The orbiter descends in this nose-high attitude all the way from orbital speed and altitude to about 40,000 feet, where the speed is down to 250 mph. At this point, the nose is lowered by abrupt downward deflection of the elevator, and after a subsequent dive to 25,000-foot altitude, during which it picks up some speed again, the vehicle assumes a normal nose-low glide flight for the final approach and landing.

Delta wing vs. straight wing. The delta-wing orbiter reenters the atmosphere at a relatively low angle of attack. As a result, its entire body is subjected to much more aerodynamic heating and requires more protection against it. On the other hand, with its low angle of attack, the delta-wing orbiter creates plenty of aerodynamic lift along with its speed-reducing drag. This gives the delta orbiter great maneuverability during the hypersonic glide through the atmosphere, and maneuverability can be translated into "cross-range."

For instance, if the delta-wing orbiter were to descend from an orbit in the plane of the equator, it could land on airfields several thousand miles north or south of the equator; whereas the straight-wing orbiter, with its very limited hypersonic maneuvering capability, could at best veer one or two hundred miles to the right or left of its reentry course.

The operational importance of cross-range capability in relation to the price one has to pay for it in weight and technological difficulties is still a matter of intense study. The answer will undoubtedly affect the orbiter configuration ultimately chosen.

As with the orbiter, there are also different concepts for the booster.

Countering reentry heat. Obviously, the materials and structural problems posed by a reusable orbiter are formidable. The underbelly of the orbiter, which is exposed to severe heating, will probably have a shingle-type skin of coated columbium (or a new-fangled alloy called TD-Nickel Chrome"), while the less-exposed upper surfaces will be made of titanium. Tantalum, or even replaceable ablation strips, may be required for areas of exceptionally high temperatures such as the nose cap or leading edges. Multiple layers of insulation will protect the cockpit, cargo bay, passenger compartment, and propellant tanks against heat influx from the hot outer skin.

In size and dry weight of its two elements, the shuttle will compare with some of the major new flight systems of our time (a Saturn V, a C-5A or SST airplane). With respect to gross lift-off weight, however, the 3½-million-pound shuttle is in a class by itself.

Landing speed of the burnt-out booster will be about 175 mph, only slightly higher than for the Boeing 747. Orbiter landing speeds will be in the range of 180 to 195 mph, comparable to the supersonic transport.

New engine foreseen. The rocket engines for both the booster and the orbiter will be throttleable hydrogen/oxygen engines of unprecedented propellant economy. It is presently hoped that a new engine of approximately 400,000 pounds of thrust will meet the requirements of both elements of the shuttle. The orbiter will need only two or three of these engines; the booster may have as many as 12 or more.

Some performance advantages can be gained if the air-breathing cruise engines, which enable the booster to fly back to the launch site, use liquid hydrogen as fuel. Whether the orbiter will also require air-breathing cruise engines for final approach and landing, and a "go-around" capability in case of an aborted landing approach in inclement weather, are questions still under study.

Missions for shuttles. As presently envisioned, the space shuttle may be used for three distinctly different types of flight missions. The first of these is a straightforward transport mission to a relatively low earth orbit. This may be a passenger-and-cargo flight to a space station, with subsequent return of other passengers and a load of data. Or it may involve the carrying of an unmanned spacecraft to a low earth orbit and its subsequent activation under the supervision of a special shuttle crew. Or you can go up to a satellite that has broken down or should be updated; this shuttle could visit it and pull it back into the cargo bay where necessary rework could be done.

Second, there will be the "sortie" type of shuttle flight. This would be indicated whenever a manned science

Spaceplane to Put You in Orbit

[Continued]

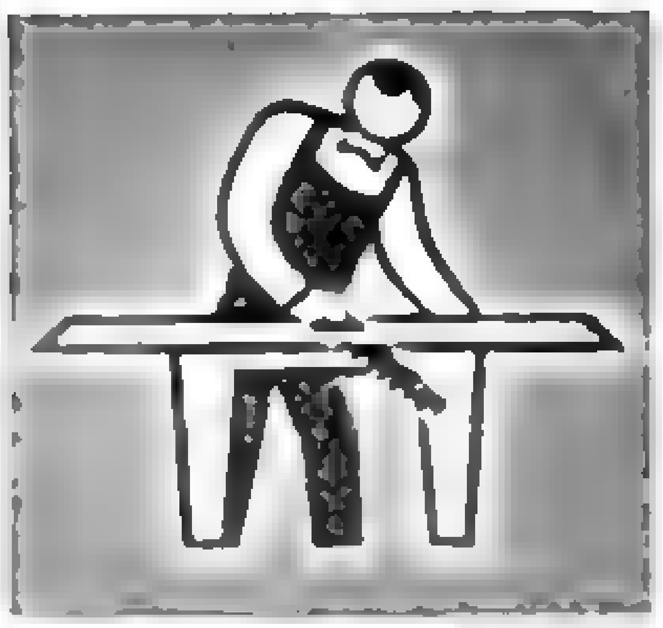
mission of limited duration is to be performed in an orbit where there is no space station. One example: a specific astronomical study that could be completed within two weeks but requires a polar orbit. The telescope would be carried in the shuttle's cargo bay along with a module in which the observers would work, live, eat, and sleep as in a house trailer.

Third, there may be the large-payload mission. Here the shuttle's manned orbiter would be replaced by an unmanned "one-way" rocket vehicle. Firing up at the normal booster staging speed of Mach 9, the wingless second rocket stage would propel either a very heavy spacecraft to a low orbit, or a lighter payload into a high-speed synchronous orbit, or a lunar or even planetary trajectory, while the manned booster returned to the launch site.

The fact that the two elements of the shuttle, when returning to the launch site, look and handle like airplanes, will greatly affect the flight-testing program. Each two-stage shuttle, while highly economical to operate, will be a costly piece of equipment. But since it is reusable many times, only a very few of them will be needed to handle the bulk of our future space traffic. Under these circumstances, it is of the utmost importance that we do not lose any shuttle boosters or orbiters during the development phase, for any such loss would be a substantial portion of the total shuttle buy.

Flight-testing plans. It is planned to begin the flight testing of both booster and orbiter separately. Each vehicle would be only lightly loaded with fuel, and would take off horizontally under the power of its air-breathing jet engines. The first flights would be strictly subsonic and concentrate on the cruise and landing characteristics. In the second flight-testing phase both booster and orbiter would again be tested separately. Each would take off vertically from the ground under its own rocket power, and these flights would explore the supersonic flight regime up to about booster-staging speed. Only in the third and final flight-testing phase would the orbiter be side-strapped to the booster and the entire two-stage configuration be launched from the ground. PS

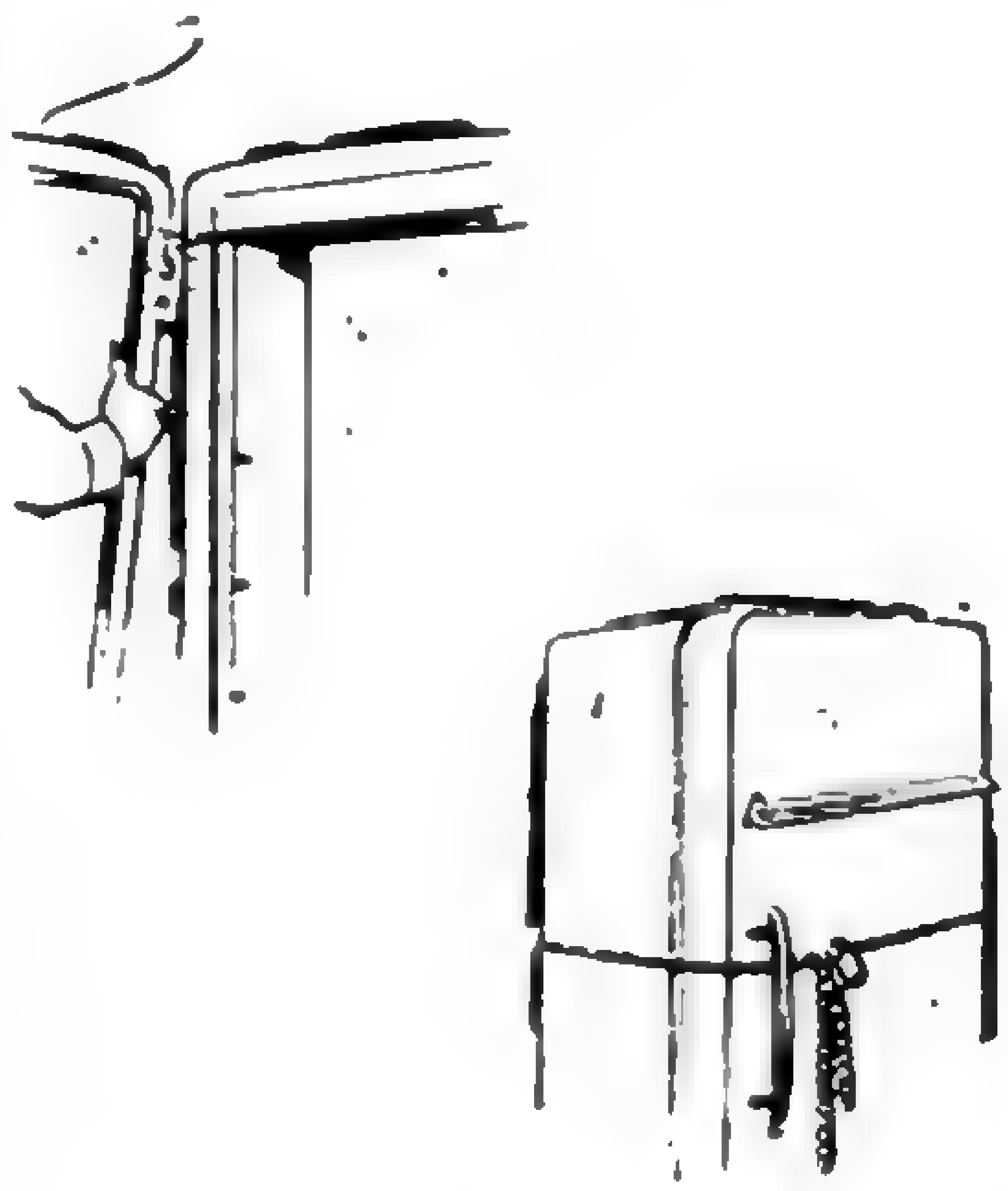
Note: As this issue went to press, NASA announced that the space-shuttle teams headed by North American Rockwell and McDonnell Douglas had been selected to carry on further design studies. — The Editors.



SHOP TALK

By ROBERT P. STEVENSON

Have you abandoned or stored a refrigerator lately?



I think we all should join in a good round of applause for the Association of Home Appliance Manufacturers, 20 N. Wacker Dr., Chicago 60606. Along with the new refrigerator I bought recently came an Association booklet warning of the entrapment dangers for small children when old refrigerators are stored or discarded. As a succession of news stories in recent years have shown, many children have suffocated inside such unused appliances while using them as a playhouse or "jail."

The booklet urges that you do one of four things: remove the door, cement on rubber bumpers to keep the door from closing completely, lock the door closed with chain and padlock, or modify the latch so the door can't close. Door removal is best, required by some towns.

Now it's Aluminum Jelly—as well as Naval Jelly

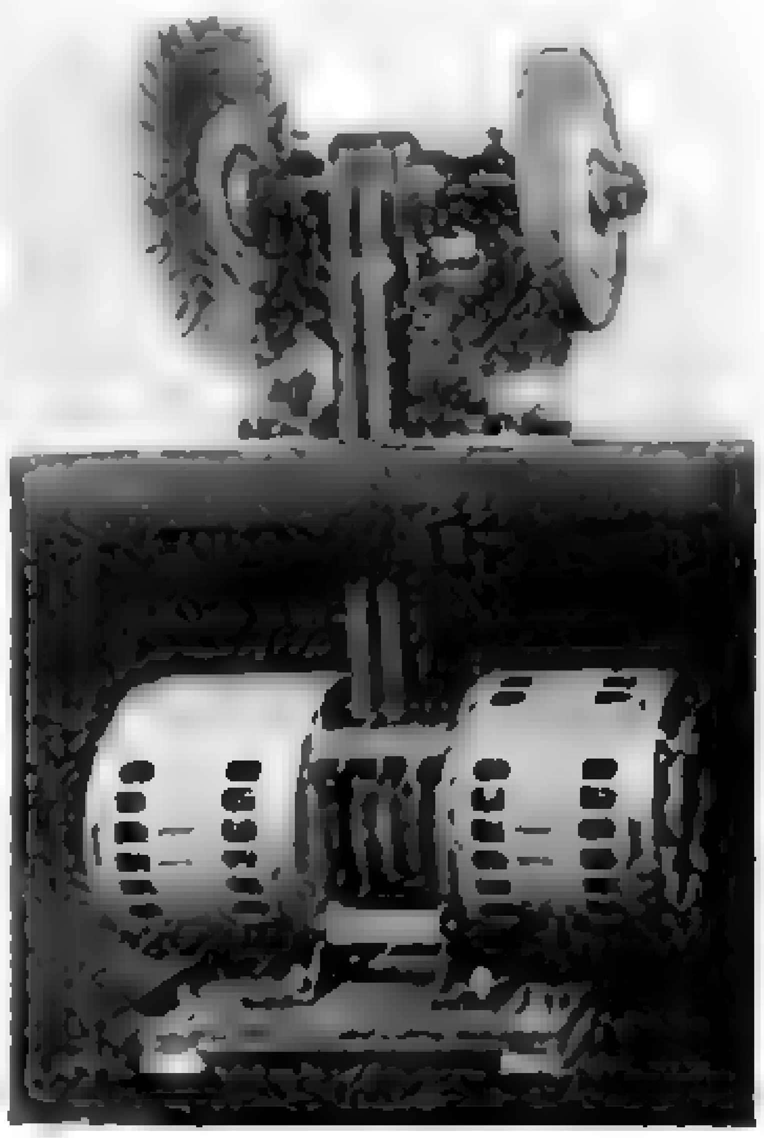
You'll find many people who swear by Naval Jelly for removing rust from iron and steel products. Now, the same company—Woodhill Chemical—offers a product, Aluminum Jelly, for brightening up aluminum surfaces. Both are available at hardware and paint stores.

Have an invention that you'd like to market?

A letter now at hand from Fenner Industries, Inc., 408 Cotton Exchange Bldg., New Orleans, La. 70130, says that company is "interested in evaluating, on a non-confidential basis, new products that can be manufactured and sold through department stores and supermarkets. We will pay the inventor a royalty on each item sold." I pass the information along without endorsement or recommendation.

How to team up two motors to drive a heavy load

Readers of Popular Science are overflowing with good ideas. One I especially like comes from Austin Armer, of Davis, Calif. As you can see in the photo (lower left), he has found a way to make good use in his shop of 1/4- and 1/3-hp electric motors from discarded home appliances. A single motor is not good for much. But team up a pair of them properly, and you double the horsepower. The two motors need not be identical in make or style, but they must have the same speed rating. One motor can even have burned-out starting windings; the other will start both. Make sure, however:



1. That the motors are rated at the same voltage, frequency, and speed. Most are 115 volts, 60 cycle, and 1725 rpm.
2. That they are set up to rotate in opposite directions when viewed from the shaft end.
3. That the motor frames are held together by four spacers long enough to leave at least one-half inch between shaft ends.
4. That two pulleys of the same diameter are installed, one on each motor shaft.
5. That belts can be installed by sliding the pulleys away from each other and inserting them one at a time between the pulleys.

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Popular Science

THE *What's New* MAGAZINE

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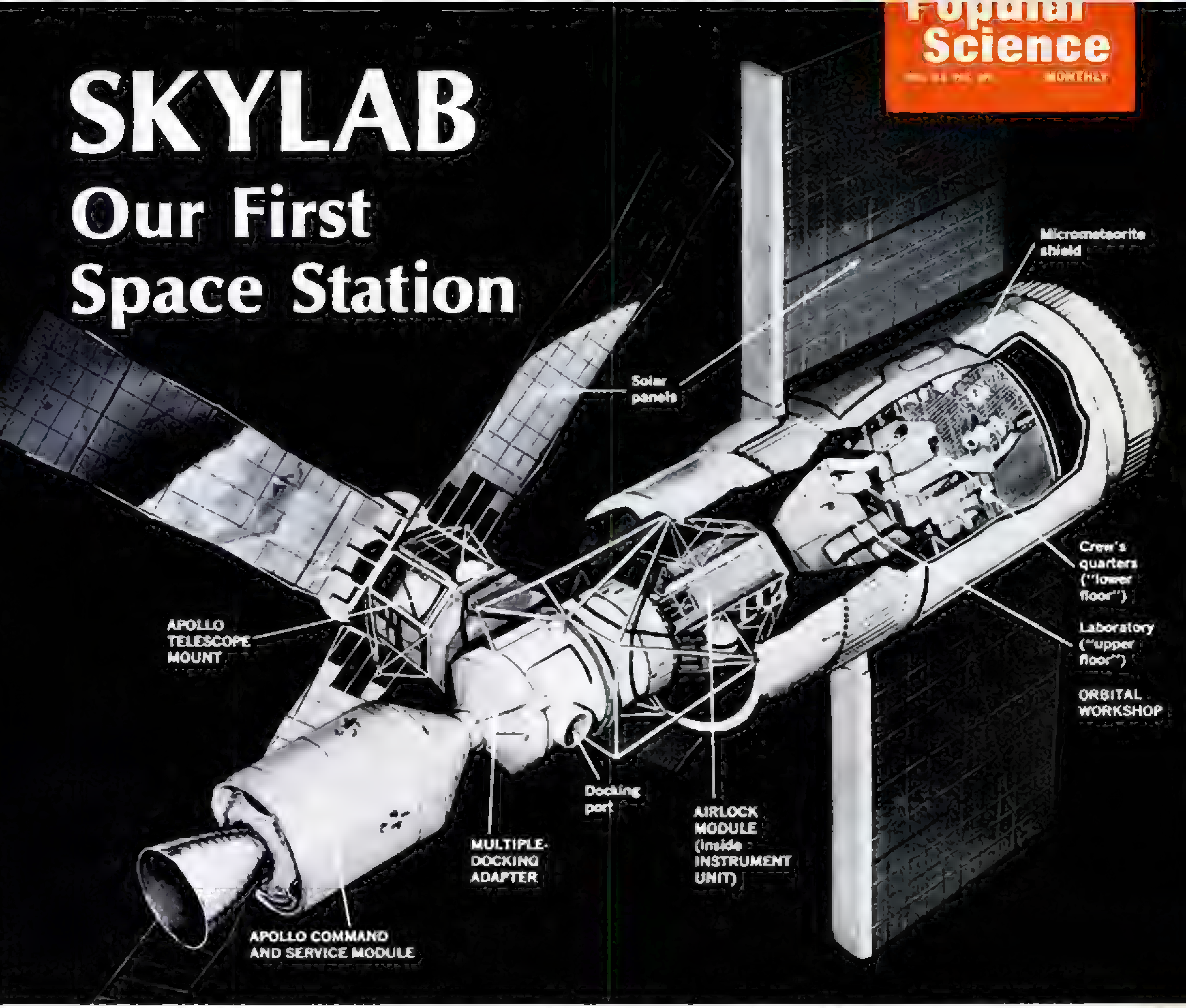
SKYLAB
Our First Space Station



Cutaway view shows Skylab in orbit. Docked to it, in foreground, is Apollo spacecraft that brings and returns its three-man crew.

Here's an advance look at our biggest manned spacecraft yet. In this 83-foot, 68-ton orbiter, due to circle 270 miles above the earth in 1972, successive three-man crews will try living under zero gravity for periods of four to eight weeks

By DR. WERNHER von BRAUN
NASA Deputy Associate Administrator
PS Consulting Editor on Space

Dr. von Braun (left) plans coming articles with PS' Ernest V. Heyn (right), Associate Publisher and Editor-in-Chief, and J. Michael Hadley, Executive Vice-President and Publisher.

By far the largest manned spacecraft we have ever built is scheduled to circle 270 miles above the earth in 1972. Three-man crews, boosted up to it in Apollo Command and Service Modules, will serve successive four- to eight-week stints aboard it. Named Skylab, it will be our first space station—a forerunner of future orbital bases for the study of the earth beneath and the heavens beyond.

With Skylab, our manned spaceflight program will take a new turn. While we are continuing our moon voyages, Skylab will herald still-longer flights. It will enrich our knowledge of earth, sun, and much else, as well. More than a dwelling in space, it offers a laboratory for all kinds of experiments in orbit.

Exploring man's limit in zero-g. Will tomorrow's long-voyaging spaceships need artificial gravity, or not? How long can men go weightless without ill effects? Skylab will probe for the answers far beyond any test yet. Gemini 7's crew spent 14 days in zero gravity; Russia's Soyuz 9 has just raised the mark to nearly 18 days. Skylab crews will go on to a 28-day

Continued

"No-hands" propulsion device for spacewalker will get a flight test in Orbital Workshop, in one of 47 Skylab experiments. Foot pedals control jets, beside feet, leaving rider's hands free for assembly of future space structures.

Overhead handrails (left) enable a weightless crewman to walk on Skylab's gridwork floors. Harness (right) keeps him from "drifting off" while asleep. In zero-g, it's comfortable to sleep upright.

Zero-gravity hand washer for Skylab crew is demonstrated by engineer pressing its water-jet button. Fixture, with openings to insert hands, confines water droplets and keeps them from becoming floating nuisances in cabin.

mission—and two more missions of up to 56 days each, if all goes well.

Striking innovations will suit the 83-foot-long, 68-ton Skylab for such extended visits.

As big as a three-bedroom house, it will provide more than 12,000 cubic feet of habitable space—nearly 40 times as much as does our next-roomiest Apollo Command Module.

It will literally have a more homelike atmosphere than any other U.S. spacecraft to date, in its main living-and-working section. Mercury, Gemini, and Apollo astronauts all have breathed pure oxygen—but medical men see risk of harm in doing it for a month or more. So Skylab will be our first spacecraft with a "two-gas" cabin atmosphere—like the air you breathe, a mixture of oxygen and nitrogen gases. However, its total pressure (five pounds to the square inch, "absolute") will be only one-third of atmospheric pressure on earth. So, to meet body needs, it will be much richer than air in oxygen: three-fourths oxygen, one-fourth nitrogen, by weight.

Skylab's design. Launched unmanned, Skylab is a cluster of five major elements: the Orbital Workshop, Multiple-Docking Adapter, Airlock Module, Apollo Telescope Mount, and Saturn V Instrument Unit.

The Orbital Workshop, actually a modified third stage of a Saturn V rocket, is the largest element—48 feet long. Its 21½-foot-diameter interior is divided by an aluminum-grid partition into two stories—the crew's living and sleeping quarters and a larger laboratory. The grid forms the floor of the lab and the ceiling of the crew's quarters, and has a central opening for passage between them. A similar grid forms the crew's-quarters floor.

By pushing lightly upward against overhead handrails, a crewman will be able to keep his footing on a floor and walk about it—an alternate way of locomotion in zero gravity to trying to float from place to place. Compartment doorways and furniture are oriented up and down to suit this procedure.

A window in the Orbital Workshop's wall enables astronauts inside to observe and photograph the earth. Small airlocks in the wall permit exposing instruments to space.

The Multiple-Docking Adapter—at the opposite end of the cluster—is the "spaceport" of Skylab, where a crew-ferrying Apollo Command and Service Module (CSM) docks to an axial port. Only one CSM will normally be docked to Skylab during occupancy. However, the Multiple-Docking Adapter has an extra port on its side where a second CSM *could* dock. This capability opens the first possibility, should trouble befall astronauts in space, of a "space-rescue" mission from earth.

The Airlock Module, bolted to the upper bulkhead of the Orbital Workshop, forms a passageway to it from the Multiple-Docking Adapter.

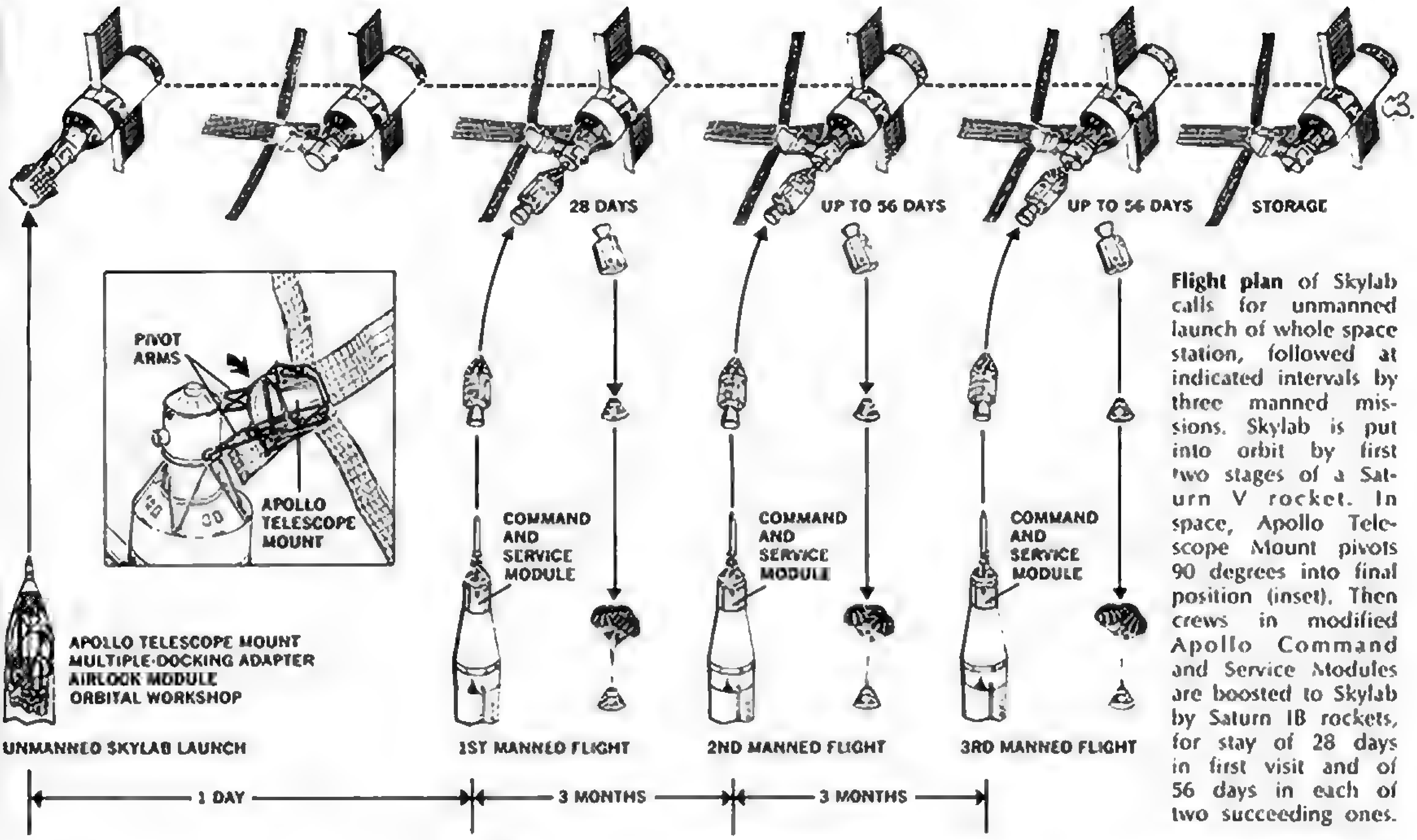
An EVA (extra-vehicular activity) hatch in the Airlock Module enables a Skylab crewman to do "space-walking" jobs outside. The very purpose of the airlock is to permit opening this hatch without necessitating depressurization of the Orbital Workshop or the Multiple-Docking Adapter.

In addition, the Airlock Module contains the gear for electric-power control and distribution to all five elements of the cluster, as well as the life-support system and an assortment of additional equipment.

The Apollo Telescope Mount (ATM) is a full-fledged manned solar observatory. It will be operated from control panels in the pressurized Multiple-Docking Adapter. However, loading and retrieving its instruments' films (which will be brought back to earth) will require trips to the ATM by space-walking crewmen.

The Instrument Unit that serves Saturn V for navigation, guidance, and control is the final major element of Skylab. Ring-shaped, it encircles the Airlock Module. It is used only during the launch phase and the first 7½ hours of orbiting:

Immediately upon arrival in orbit, the gyroscopic platform in the Instrument Unit causes the entire cluster to rotate until it is broadside to the sun. In this position, the Orbital Workshop deploys its two 600-square-foot solar panels, attached to it like gigantic elephant ears. They supply the station with about 12 kilowatts of electric power.



Flight plan of Skylab calls for unmanned launch of whole space station, followed at indicated intervals by three manned missions. Skylab is put into orbit by first two stages of a Saturn V rocket. In space, Apollo Telescope Mount pivots 90 degrees into final position (inset). Then crews in modified Apollo Command and Service Modules are boosted to Skylab by Saturn IB rockets, for stay of 28 days in first visit and of 56 days in each of two succeeding ones.

The Instrument Unit also provides sequencing signals to rotate the ATM 90 degrees from stowed to operating position, and to deploy the ATM's windmill-like solar panels. They give the ATM its own power supply of 10½ kilowatts.

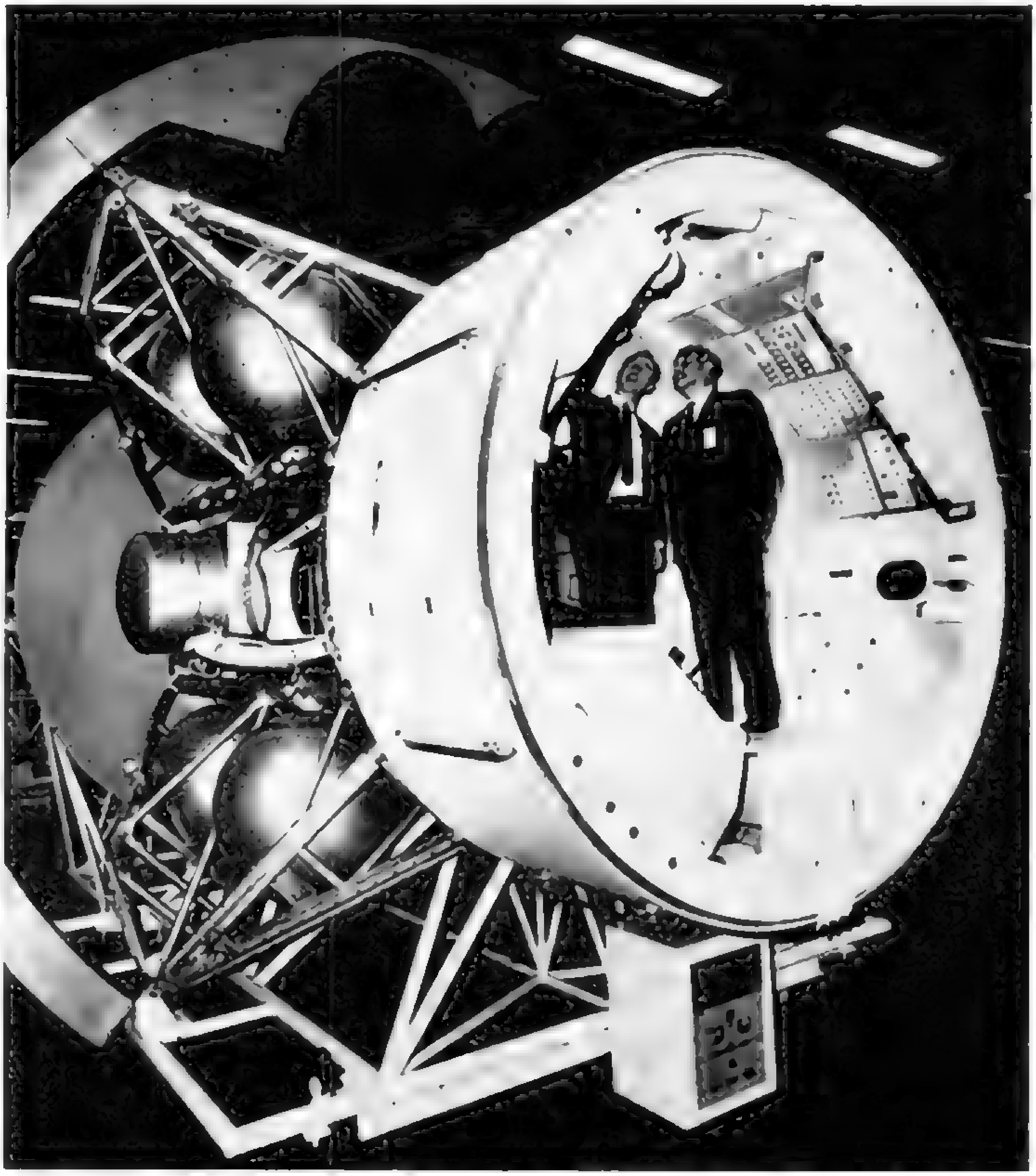
Once the ATM is in operation, a novel flywheel attitude-control system in it keeps the entire cluster in its sun-oriented attitude. This is necessary not only for solar observations and the solar-cell power supply, but also for the station's overall thermal balance.

In preparation for its three-man parties of guests, Skylab will be stocked with a 140-day supply of food, and enough breathing gases and water for still longer. For sleeping accommodations the Orbital Workshop provides a compartment where a crewman will zip himself up, sleeping-bag-style, in a wall-anchored harness—so as not to float about while he slumbers. Food-preparation and waste-disposal facilities complete Skylab's ample equipment for extended housekeeping in orbit.

What they'll do in Skylab. The Skylab program's specific objective is to conduct 47 different experiments in space medicine, crew operations, technology, earth resources, physics, and astronomy. Just a few examples must suffice here to illustrate their variety and ingenuity.

Effects of weightlessness on Skylab crewmen will be constantly monitored

[*Continued on page 124*]



Full-scale mockup of Skylab airlock, through which crew pass on way from the Apollo "ferry" craft into the Orbital Workshop, is inspected by Dr. von Braun (right).

[Continued from page 53]

by tests of their heart rate, blood pressure, metabolism, bone and muscle changes—and weight, since loss of weight has been noted after prolonged zero-g flights.

"Weighing" a weightless man. How do you weigh a crewman while he's weightless? Skylab will do it with a spring-loaded reclining chair that oscillates horizontally, with a man in it, when it is moved a measured distance off center and released. The chair's motion is gauged by a photo-optical pickup and a timer—and the subject's mass (which determines his weight on earth) is figured from the simple formula, "force equals mass times acceleration."

- A novel indoor flight test in Skylab's Orbital Workshop will try out a "no-hands" jet-propulsion unit for a spacewalker. Strapped to a saddle-like seat, he operates the thrusters with foot pedals—so his hands will be free for assembly and maintenance of future space stations. The jets, of pure oxygen, won't impair Skylab's cabin atmosphere—in fact, they'll provide make-up oxygen to replace leakage.
- Six electric cameras with synchronized shutters, peering down at the earth as Skylab sails overhead, will carry out an advanced experiment in "multispectral" photography of earth resources. Using this technique, coming earth-resources satellites will speed the gathering of world-wide data on available food crops, timber, oil and mineral deposits, and other terrestrial answers to human needs [PS, July '67].
- A test chamber on the Multiple-Docking Adapter's wall will serve for first trials of zero-g metal casting and other processes that could lead to the manufacture in space of valuable new products—like hollow ball bearings, and light-as-balsa "foam" steel [PS, Dec. '69].
- Is fire hazard in a spacecraft diminished by zero gravity—which shrinks flames into weird little balls and so may check their spread? Only brief trials in parabolic airplane flights have been feasible so far [PS, June '67]. A Skylab experiment chamber will thoroughly investigate the effect of zero-g on spacecraft materials' flammability.
- Experimenters will measure how much the crew's movements in Skylab affect its steadiness and high-accuracy telescope-pointing from it.
- Most important of Skylab's science experiments will be unprecedented observations of the sun with the Apollo Telescope Mount. From orbit, its battery of telescopes will be able to observe and photograph the solar disk by radiation that cannot penetrate the atmosphere and be recorded on earth [PS, Jan. '68]. Scientists eagerly await the revelations of ATM photographs of the sun by its x-ray and far-ultraviolet radiation, for example. Stellar and galactic observations will round out Skylab's astronomical experiments.

The flight plan. Skylab's unmanned launch from pad 39 at Cape Kennedy will use the first two stages of a Saturn V rocket. Skylab itself, instead of a third stage, will sit atop them.

The decision last year to launch Skylab with a Saturn V, instead of a smaller Saturn IB as first intended, has revised both its flight plan and design. In the earlier scheme, the Saturn IB's spent upper stage was to become the Orbital Workshop. In orbit, the crew would have had to make the emptied liquid-hydrogen tank habitable, by shifting furniture and equipment to it from the Multiple-Docking Adapter. Then the ATM—

with a modified Apollo Lunar Module for a manned control room—was to be boosted up to a rendezvous with it.

With Saturn V it now becomes possible to launch the Skylab cluster all at once—"dry," fully outfitted, and requiring no furnishing in orbit to ready it for occupancy. Putting the ATM's controls in the Multiple-Docking Adapter now dispenses with the ATM's Lunar Module "cab."

The launch will put Skylab into a nearly circular orbit, inclined 50 degrees to the equator. This means that it will overfly places on earth between 50 degrees North and South latitude. It will get as far north as the center of Hudson Bay, and Liverpool; in the southern hemisphere it may occasionally streak over the southern tip of Argentina.

Up goes a crew. The first manned mission will take off a day later. Launched by a Saturn IB vehicle, from a new tower mounted on one of the Kennedy Space Center's Mobile Service Structures, a modified Apollo CSM with a three-man crew will first go into an elliptical orbit of 93 by 138 statute miles. In the fourth orbit the CSM—now separated from the Saturn IB's second stage—will fire up its own Service Module engine. It will climb to Skylab's 270-statute-mile height, rendezvous, and finally slip into the Multiple-Docking Adapter's axial docking port.

The crew will pass through the Skylab cluster to the Orbital Workshop and activate it for habitation. The CSM will be powered down to about one kilowatt, which it will henceforth draw from Skylab's solar cells. Even in the "dormant mode," this much power is required to keep the CSM's thermal-control system operative, permit the reading of certain monitoring instruments in the Command Module, and retain a CSM communications link with the earth for emergencies.

The first crew's work during their 28-day stay will center on medical experiments, and evaluation of Skylab's habitability systems. They also will turn on the ATM experiments and verify that they work properly. Before returning to earth, the crew will prepare Skylab for orbital storage. On the 29th day, the CSM will cast off, retro-fire its Service Module engine to de-orbit, and reenter the atmosphere for a splashdown in the western Atlantic.

Next, longer stays. The second manned mission will take off about 90 days after the first one, and will rendezvous and dock with Skylab the same way. This time the emphasis will be on the ATM and observations of the sun. If no medical or other difficulties arise, the crew's stay will be extended to 56 days.

Finally, the third manned mission will start about 90 days after the launch date of the second. It will complete the science program, tie up any loose ends, and provide much-needed additional data on man's medical response, adaptability, and performance during two months of weightlessness. This flight will also last up to 56 days.

Then Skylab will go into orbital storage—to be reactivated at any subsequent time, should future plans call for further visits.

Skylab, of course, is only a beginning—a precursor to more elaborate future stations of vastly enhanced capability and usefulness. But success with even half of the scientific, technological, and operational tasks assigned to the Skylab program will make a profound contribution to man's ability to put to use his new foothold in space.

NOVEMBER 1970 50 CENTS

Popular Science

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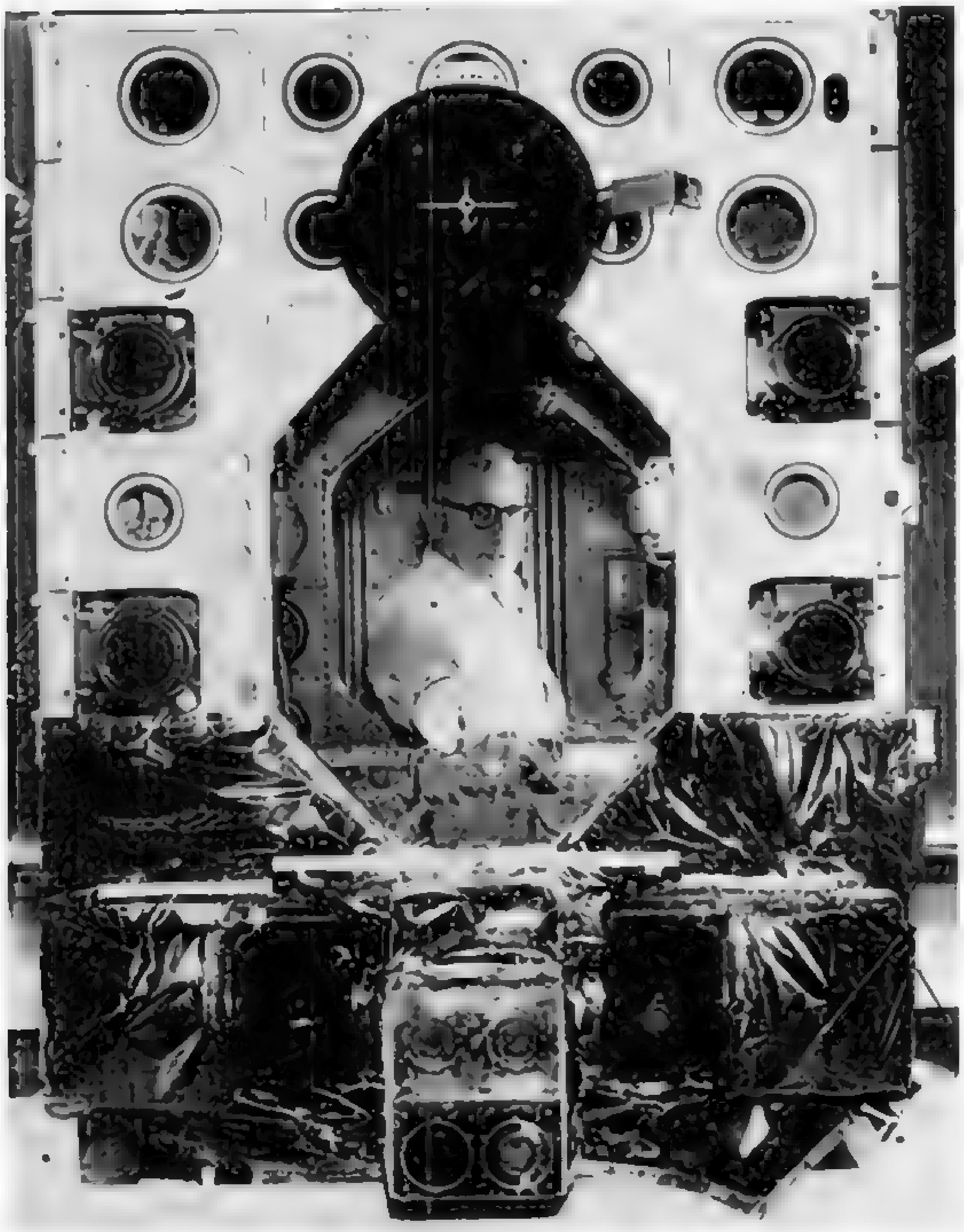
How New Weather Satellites Will Give You More Reliable Forecasts

By DR. WERNHER von BRAUN
NASA Deputy Associate Administrator
PS Consulting Editor on Space

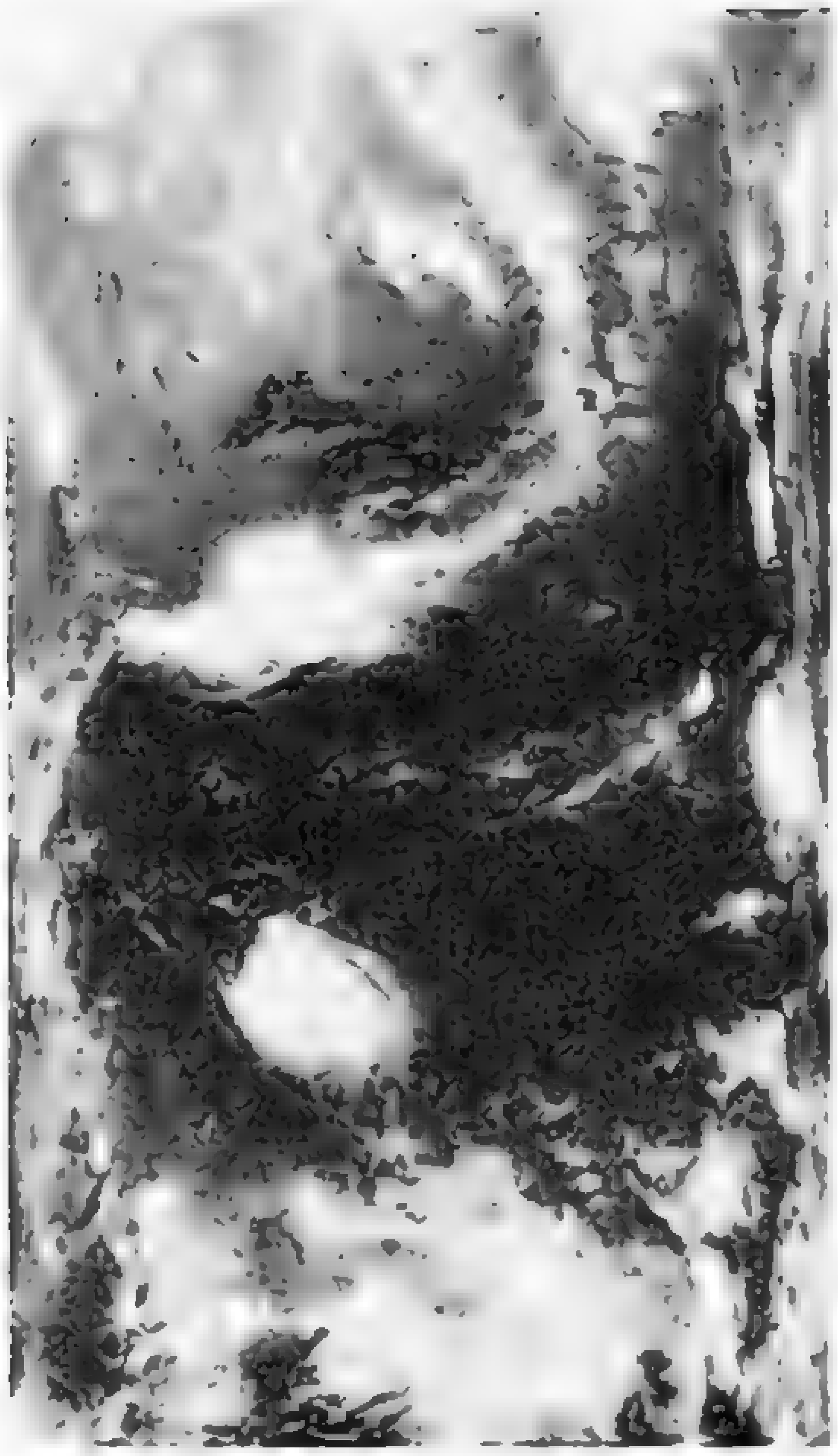
The new operational ITOS "second-generation" system promises better and longer-range predictions—and soon you'll be able to plan a good-weather vacation two weeks in advance

Ten years have elapsed since TIROS-1, our first weather satellite, opened a new era in meteorology. In less than another 10 years, weather satellites will tell you whether you will have a rainy vacation if you leave two weeks from now.

Since April 1, 1960, 23 meteorological satellites have returned more than a million pictures of the earth's cloud cover, and a wealth of other data for weather forecasting and research. During those 10 years, weather satellites



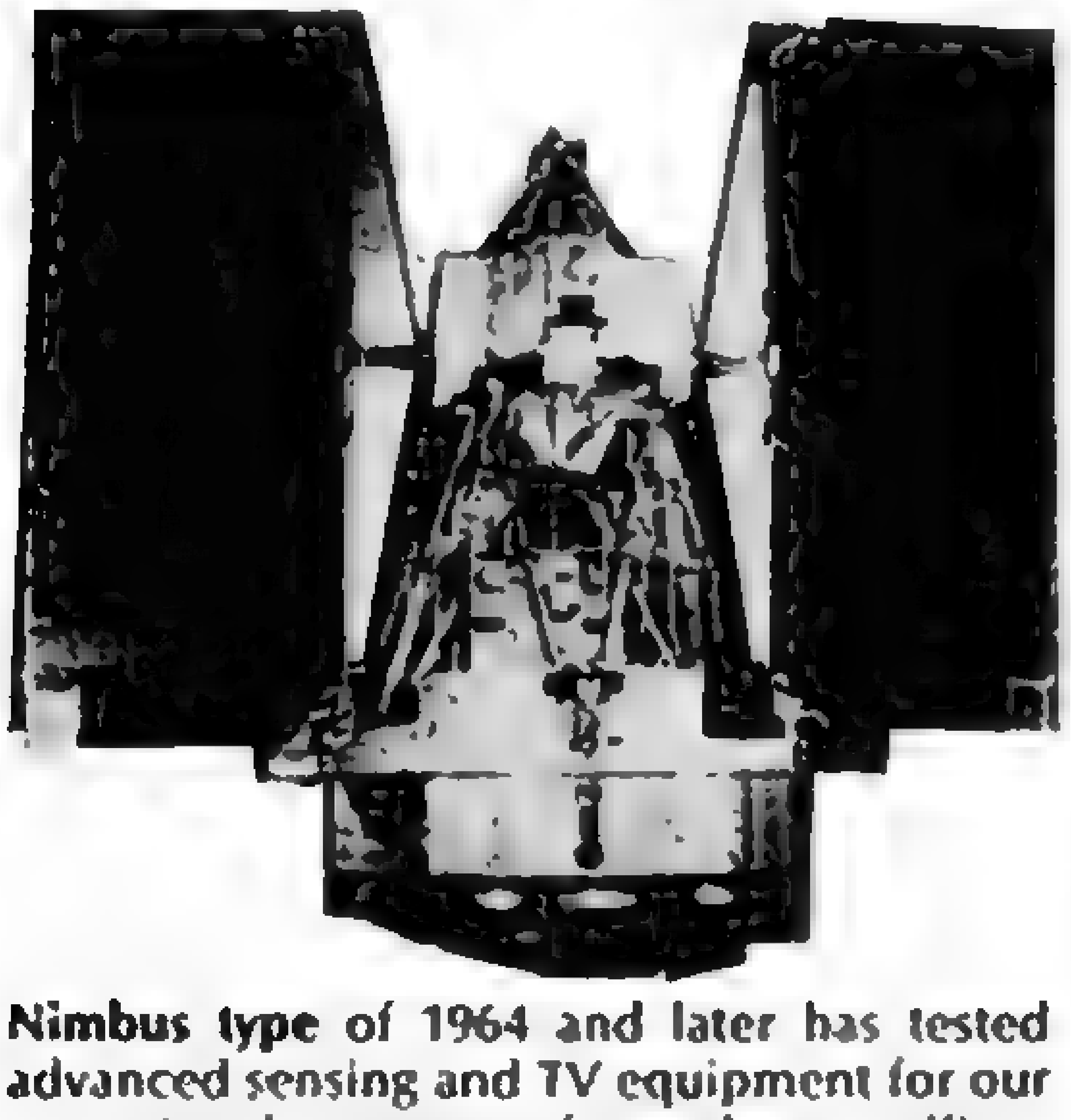
Newest weather satellite is boxlike, RCA-built ITOS-1. It views earth's clouds by day with four TV cameras (at left and right of opening); by night, with two scanning infrared radiometers (on each side of flat-plate radiometer at center of bottom), like one seen close-up in top view at right. Flywheel, in view at lower right, helps keep the camera-studded side of ITOS-1 facing earth.



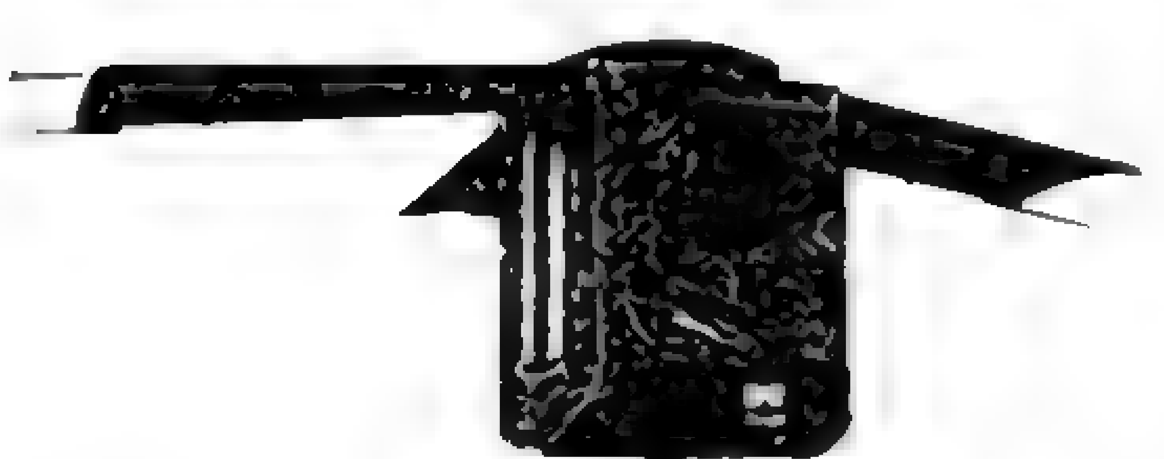
In total darkness, Hurricane Celia of 1970 (the white mass near lower center) is spotted off Texas coast by ITOS-1 satellite.

Ten Years of Weather Satellites

Hatbox-shaped TIROS-1 of 1960, first of our weather satellites, was experimental version.



Nimbus type of 1964 and later has tested advanced sensing and TV equipment for our operational systems of weather satellites.



ITOS satellite of 1970 is a prototype of ESSA's new fleet of Improved TIROS Operational Satellites for weather watching.

have saved countless lives through early hurricane warnings. They have helped airline pilots circumnavigate storm fronts over oceans and thinly populated areas. They have aided shipping by revealing ice conditions in northern passages and in bays and estuaries. And still better satellite weather forecasting is on the way.

Not only will this aid your personal planning; it will be worth money. An accurate five-day forecast probably would save between $2½ and $5½ billion yearly in the U.S. alone, and perhaps $15 billion for the entire world. Most of the savings would be in agriculture, the construction industry, and government operations such as flood control and water management of hydroelectric lakes. Since the capital investment for a good global weather-forecasting system should be less than a half-billion dollars, the payoff is impressive.

How weather satellites began

First orbital pictures of the earth's cloud cover, crude but encouraging, were obtained by Explorer 7—a 92-pound wheel-shaped satellite developed for NASA by the Army Ballistic Missile Agency, and orbited by a three-stage Juno-2 rocket in October 1959.

TIROS-1 was designed to get down to serious work in weather observation. It was the first of a spectacularly successful TIROS family of 10. "TIROS" stands for Television Infrared Observation Satellite—and, from TIROS-2 on, all carried infrared sensors to measure heat radiated by the earth's surface, in addition to their TV cameras.

In 1963, TIROS-8 was the first to use a new camera system—the Automatic Picture Transmission (APT) system—whose cloud pictures could be received by small inexpensive ground stations.

TIROS-9 of 1965 introduced another radical improvement. Earlier TIROS spacecraft could observe only about 20 percent of the earth's surface in one day. Their sensors and TV equipment looked out through the base of the wheel-shaped, spin-stabilized spacecraft, and pointed away from the earth much of the time. Even when they could view the earth, they seldom looked straight down; to interpret data meaningfully, coordinates had to be transformed.

Instead, TIROS-9 carried its two cameras in the wheel's rim, 180 degrees apart. Orbiting on its side, it rolled around the earth like a wheel, pointing first one camera and then the other at the earth. Its polar orbit, putting the sun behind the cameras viewing sunlit earth, constantly shifted westward due to the earth's rotation. Thus TIROS-9 could photograph the entire sunlit surface of the earth each day.

The time for weather satellites to "go operational" had clearly come.

First operational system

On Feb. 3, 1966, ESSA-1 went into orbit. ESSA stands for the Department of Commerce's Environmental Science Services Administration, then newly created, with which the U.S. Weather Bureau had been consolidated. Now that NASA had demonstrated the feasibility of real-time meteorological observations from orbit, ESSA assumed the role of putting that new capability to work.

Since ESSA took over, no major storm on earth has gone undetected. Warnings based on satellite data have averted innumerable deaths, injuries, and losses of property. In one dramatic instance in 1968, ESSA-6 was credited with saving the Mexican cities of Gomez Palacios and Torreon when its weather pictures, from a height of about 900 miles, helped Mexican authorities manage a reservoir that threatened to break its dam and inundate the two cities.

Under ESSA's aegis, the Automatic Picture Transmission system has become so popular that 510 APT ground receivers are now in operation in more than 50 countries. At international airports they serve for the weather briefing of transoceanic-flight crews. The Air Force has found the satellite pictures helpful to detect local breaks in bad weather, for otherwise-impossible ground-support operations.

NASA tests refinements

While TIROS satellites evolved into the operational ESSA system, NASA experimented with more-advanced sensing and TV systems. These went aboard non-spinning Nimbus spacecraft—easily three times as heavy as the TIROS/ESSA satellites, but offering the advantage of a stable earth-looking platform.

Nimbus 1, launched in August 1964, carried an Advanced Vidicon Camera System (AVCS)—which, along with the popular APT system, soon became standard equipment in ESSA satellites—and a High-Resolution Infrared Instrument that made night cloud photography possible.

Besides a nuclear power source to recharge its chemical batteries, Nimbus 3 tested two new instruments—a Satellite Infrared Spectrometer and an Infrared Interferometer Spectrometer. Together, these measured temperature and atmospheric pressure at various levels in the atmosphere. The soundings closely matched measurements from airplanes at low altitudes, and appeared even more accurate

than balloon-radiosonde measurements at high altitudes. Since a single satellite can cover all regions of the globe and transmit its readings at once to weather-data centers, this new measuring method can be considered a major advance.

Relaying unmanned network's data

Weather satellites' usefulness would be enhanced if, besides making direct observations, they could collect and relay information from unmanned ground stations, buoys anchored or drifting at sea, and balloons drifting through the air. On radio command from the satellite as it rose above the local horizon, the stations below would transmit data recorded during the preceding hours. The exact position of drifting stations would be determined by the satellite. Feasibility of this idea was successfully demonstrated by Nimbus spacecraft with a system called IRLS (Interrogation, Recording, and Locations System).

NASA's multi-mission Applications Technology Satellites 1 and 3, hovering stationary in synchronous orbit more than 22,000 miles above the earth, carried out other experiments to improve meteorology from space. ATS-1, orbited above the Pacific in December 1966, photographed the earth's whole disk every 20 minutes with its Spin Scan Cloud Camera. A sequence of these views, put together, yielded a short movie that dramatically displayed the changing cloud pattern on the earth below.

ATS-3, in November 1967, carried a Spin Scan Cloud Camera for color pictures into orbit above Latin America. From this location, in a joint ESSA-NASA experiment, it continuously photographed the earth at times of high tornado probability. One of its pictures was taken at almost the same time (April 19, 1968, 3:13 p.m. CST) that a tornado struck the town of Greenwood, Ark.—killing 14 persons, injuring 270, and causing extensive damage. The tragic event led to a thorough after-the-fact analysis to study what triggered this and other tornadoes. ESSA experts now are optimistic that a time will come when satellite pictures will enable them to predict a tornado and its path.

Newest operational satellites

Last January the first of a fleet of ESSA's second-generation weather satellites went into 900-mile-high orbit. ITOS-1 (for Improved TIROS Operational Satellite) incorporates the latest refinements in sensors and television equipment.

Four-foot-high, 682-pound ITOS-1 has a "wingspread" of 14 feet with its three solar panels unfurled for 500 watts of power. A flywheel and electronic circuitry provide a precision attitude-control system replacing TIROS spin stabilization.

ITOS-1 has two wide-angle high-resolution AVCS cameras, two APTs, and two scanning infrared radiometers for nighttime cloud pictures. It also carries a novel flat-plate radiometer, which can tell whether a particular part of the earth is absorbing more heat than it loses—an important piece of information for long-range forecasts. A solar-proton monitor can predict solar flares that may be hazardous to manned space flights or may interfere with radio on earth.

Long-range weather forecasts

Reliable long-range weather forecasting will take more than a continuous survey of the atmosphere from orbit. To forecast, we must better understand the underlying mechanisms that make the weather. The most important single factor is the interaction between the atmosphere and oceans. Seventy percent of the globe is covered by water, which is pumped about by the earth's rotation in great "rivers" like the Gulf Stream and the Humboldt Current.

We need to know more about the complex energy balance involved as water from this dynamic ocean system evaporates, forms clouds, is borne inland by the wind, and returns in rivers to the seas.

An international program called GARP (Global Atmospheric Research Project), which NASA and ESSA support, has been established to throw light on these fundamentals. A U.S. contribution to it has been a $23 million, three-month Barbados Oceanographic and Meteorological Experiment (Bomex) in the western Atlantic off Barbados [PS, Aug. '69].

Fast high-capacity electronic digital computers make it possible, too, to "model" weather situations on a computer. If we could set up the physical laws governing weather in a computer, and it was fast enough to stay ahead of the weather, we should know at any time what weather to expect.

Today, while we know the general equations, we do not know many of the numerical figures we would have to feed into the computer. But if we combine a continuous global satellite survey of the atmosphere with an advanced computer-modeling technique, and continuously update the computer with real-time factual weather information, we are bound to get ahead of the game.

It is safe to predict that a reliable five-day weather forecast, and even a respectable 14-day forecast, will be available 10 years from now.

Turning Satellite Photos into Weather Forecasts

Weather photo is received by radio at the Suitland, Md., facility of the Environmental Science Services Administration (ESSA).

Tracing frontal systems with the aid of satellite photos, ESSA technicians at Suitland plot the world's weather on charts.

Hurricane-warning centers are alerted to late developments by meteorologist on phone with maps and photos at Suitland.

TV brings you timely forecasts of local, national, and world weather based on data from weather satellites orbiting earth.

1971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Grand Tours by unmanned TV spacecraft, in the late 1970s, can reach a trio of the farthest members of the solar system in a single trip

How We'll Explore the Outermost Planets

By DR. WERNHER von BRAUN *NASA Deputy Associate Administrator*
PS Consulting Editor on Space

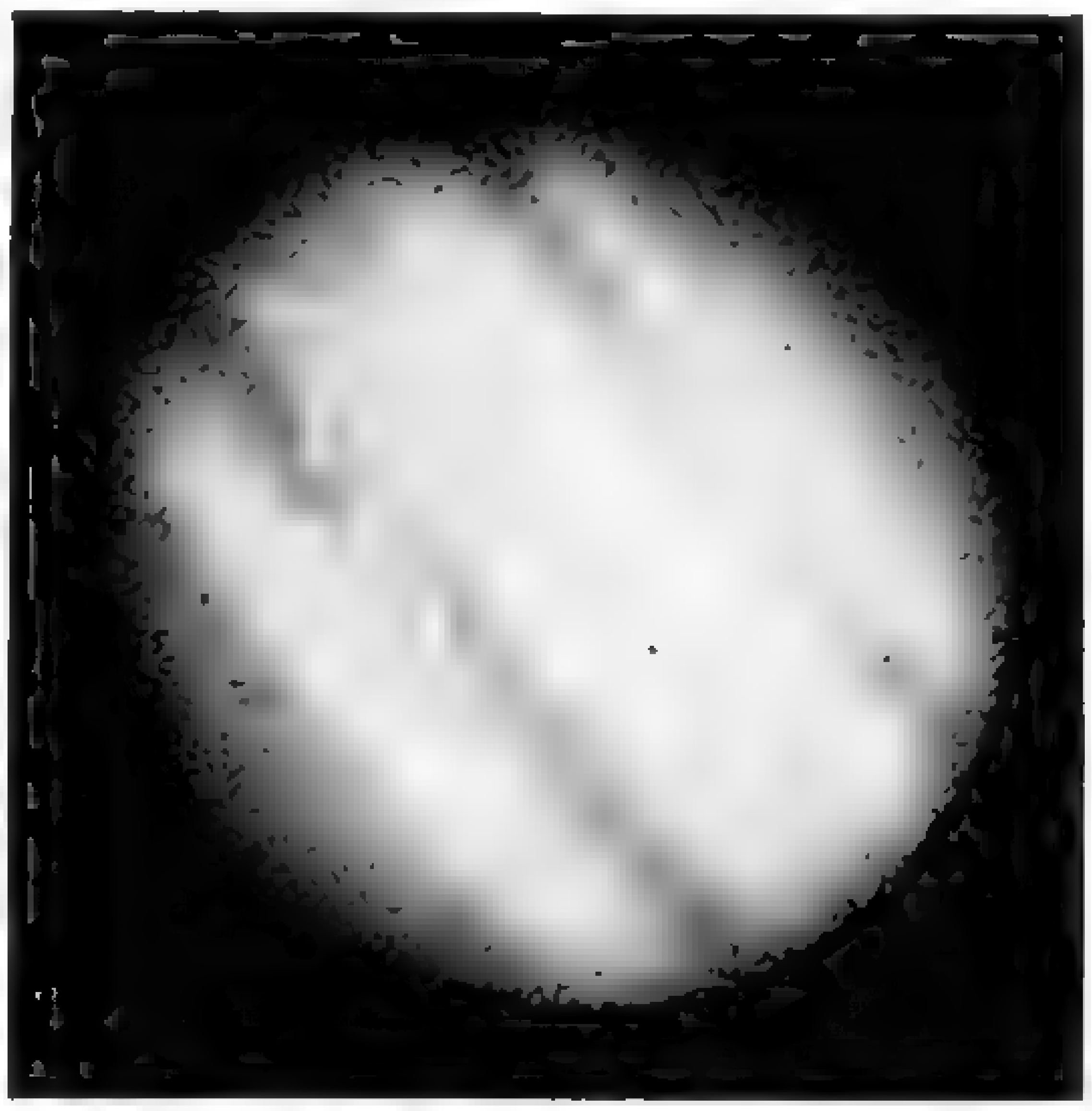
In the latter part of the 1970s, Congress and the American taxpayer willing, NASA will launch four unmanned TV spacecraft on "Grand Tours" that will visit every one of the outer planets of our solar system—the ones beyond Mars and the asteroid belt.

Specifically, 1976 and 1977 will see one launch each of a spacecraft that will fly past Jupiter, Saturn, and farthest-of-all Pluto. Two twin spacecraft will be launched in 1979 to Jupiter, Uranus, and Neptune.

What makes so venturesome an exploring program possible and urgent is an exceptionally favorable alignment of the planets, which will not occur again until well into the 22nd Century. Without its help, a spacecraft flight by the most economical or fuel-conserving path to Pluto—never closer to us than 2,670 million miles—would take a prohibitive 41 years. By taking advantage of the planets' unique line-up in the late Seventies, we can reduce this flight time to less than nine years.

Moreover, the craft can visit both Jupiter and Saturn on the way, and can do all this with no more fuel, rocket power, and escape speed—36,000 mph—than would be required for a flight just to Jupiter alone.

A boost from Jupiter. The secret of the amazing multiple payoff offered by these Grand Tour missions lies in the "gravity-assist" rendered by the giant planet Jupiter, with 318 times the earth's mass.



Mighty "engine" to accelerate a Grand Tour interplanetary spacecraft will be the planet Jupiter, largest in solar system. Pull of orbiting planet's gravity will catch up craft and "snap the whip" with it, slinging it onward toward Saturn or Uranus according to flight plan. NASA photo shows Jupiter as seen from 80,000 feet above the earth by 36-inch telescope of Stratoscope II balloon last March.

Jupiter orbits around the sun at a speed of about eight miles a second, or 29,000 mph. A spacecraft approaching Jupiter's trailing edge at relatively low speed will be caught up and yanked along by the mighty pull of Jupiter's gravitational field. When the craft ultimately escapes the planet's grip, a portion of Jupiter's energy of motion around the sun will have been conveyed to it—and so the craft leaves Jupiter's field at higher speed (with respect to the sun) than it entered it.

In other words, Jupiter's gravity acts upon the spacecraft just as the accelerating blast of an extra rocket stage would—but with the vast difference that no fuel is consumed in the process. It is this Jupiter gravity-assist that hurls the Grand Tour spacecraft onward to the farther planets—either Saturn and Pluto, or Uranus and Neptune.

In similar fashion a Grand Tour spacecraft will get another gravity-assist boost, although a substantially weaker one, from the next planet encountered en route.

These boosts a Grand Tour spacecraft will get, along the way, put its needed initial speed well within our capability. The projected three-stage launch vehicle is to be a Titan III D-Centaur with a solid-propellant Burner II third stage.

The Grand Tour spacecraft. Every aspect of the design of the outer-planet spacecraft is governed by the tremendous distances and long travel times—1½ to 2¼ years just to reach Jupiter, the nearest objective.

Beyond Jupiter the distant sun's radiation is so feeble that arrays of solar cells—popular sources of electric power for most contemporary spacecraft—become hopelessly ineffective. In addition, the diminished heat flux from the sun calls for active heating of critical spacecraft elements—and the great distances demand extra power for radio transmitters.

Hence the spacecraft will get its power from radioisotope thermoelectric generators (RTGs), fueled by radioactive plutonium 238, like the observing-instrument packages left on the moon by Apollo astronauts. In turn, this gives the projected Grand Tour spacecraft the name of TOPS, which is short for *Thermoelectric Outer-Planet Spacecraft.*

Larger than the Mariner spacecraft that have gone to Mars and Venus, each TOPS will weigh about 1,500 pounds. It will have a hydrazine-burning engine of 25 pounds' thrust for midcourse corrections, and hydrazine attitude-control thrusters.

Its external appearance is dominated by a 14-foot-wide dish antenna, designed to beam the radio signals back to earth—across distances so vast that a signal will take 36 minutes to reach the earth from the vicinity of Jupiter, and a whopping four hours from Pluto, compared to 1¼ seconds for moon-to-earth distance.

Athwart the spacecraft extends a 30-foot handlebar. At one end the bar carries TV cameras with narrow- and wide-angle lenses, for close-up views of the planets as TOPS flies by, and other scientific instruments.

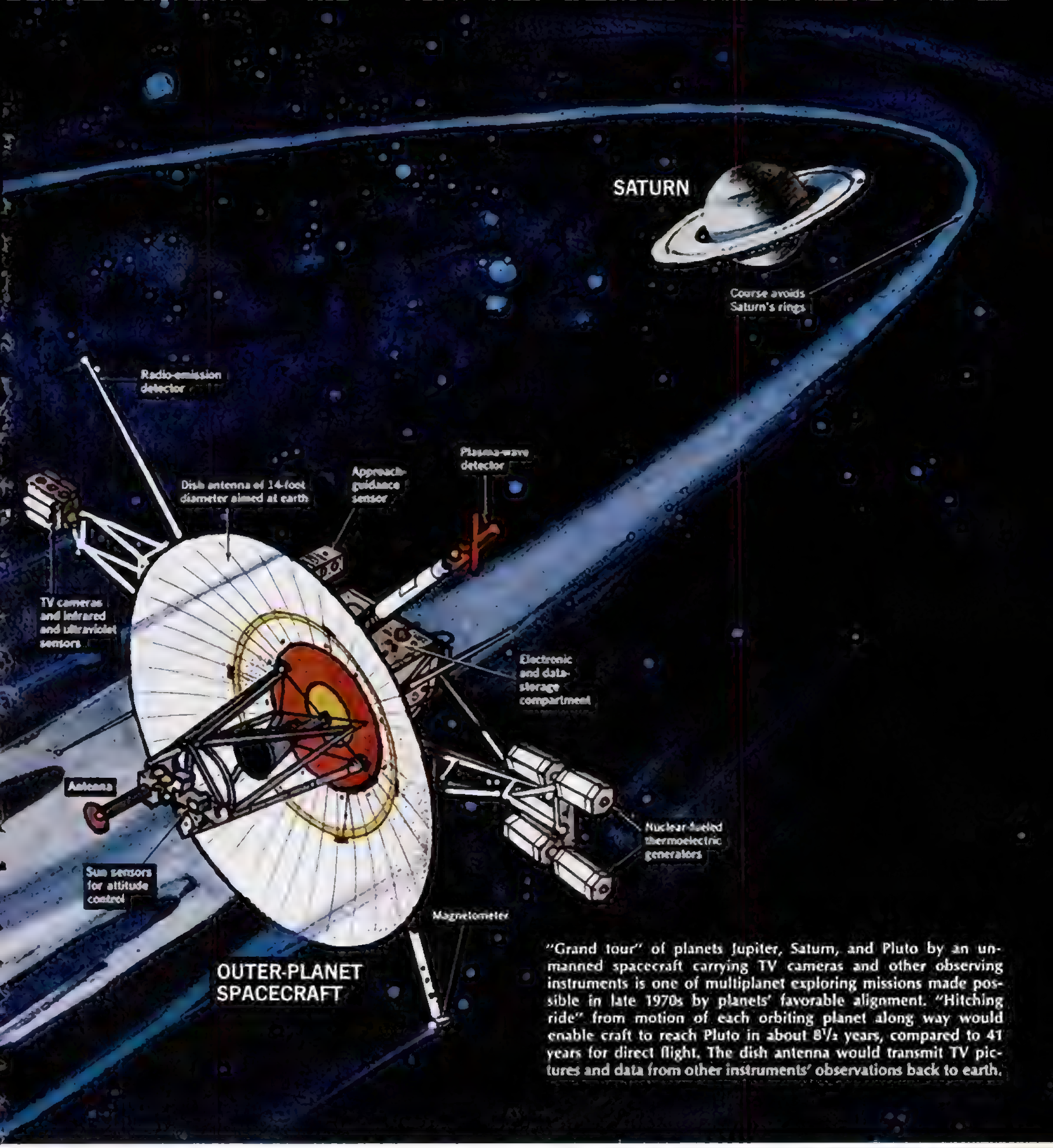
At the other end of the handlebar is an array of four RTG power units. In all they furnish 400 [*Continued*]

ILLUSTRATION BY BOB McCALL

watts of electricity. This amount of power is needed for the scientific instruments, a radio-command receiver, telemeter and TV transmitters, thermal and attitude control, and a highly sophisticated computer.

If a telemeter signal from a craft at Pluto's distance showed a corrective signal should be flashed back to it—say, to change its attitude or to turn equipment on or off—the round trip for telemeter and command signals would take eight hours! In that time a lot can go wrong. TOPS may start to tumble, or a short may destroy vital circuitry. The answer is a novel concept—STAR, a *S*elf-*T*esting *a*nd *R*epairing Computer, which can make a fault analysis and a remedial decision on the spot. STAR also controls TOPS' data-processing system and its guidance and control system.

Of course, for TOPS to intercept planets beyond Jupiter, the Jupiter gravity-assist must be applied with utmost precision. This is accomplished by an ultra-precise entry into Jupiter's field, involving active "target acquisition" of Jupiter by the approaching spacecraft: Its navigation sensors, hitherto trained on the sun and the bright star Canopus, now pick up the planet and determine its bearing, while the spacecraft's attitude remains, temporarily, on gyro control only. One or more



"Grand tour" of planets Jupiter, Saturn, and Pluto by an unmanned spacecraft carrying TV cameras and other observing instruments is one of multiplanet exploring missions made possible in late 1970s by planets' favorable alignment. "Hitching ride" from motion of each orbiting planet along way would enable craft to reach Pluto in about 8½ years, compared to 41 years for direct flight. The dish antenna would transmit TV pictures and data from other instruments' observations back to earth.

midcourse corrections follow. The same technique serves at the next planetary encounter.

Active target acquisition and approach corrections not only ease the accuracy requirements for gyros and other elements of TOPS' guidance system. They also take care of uncertainties in the planets' positions and gravitational fields' strength, and possible flight-path perturbations by the planets' moons.

Flight times of eight to 10 years for Grand Tour missions pose an unprecedented challenge to the designers of TOPS. No comparable spacecraft has ever demonstrated that it can work that long, nor is there time enough left to demonstrate it now. The only conceivable answer is "telescoping the test procedure"—by applying a tougher-than-real test environment and by compressing the total number of switching operations and subsystem activations into a shorter time frame.

What craft will reveal. Grand Tour spacecraft promise our first exciting close look at worlds far different from the planets near us. Primeval atmospheres such as our earth may once have had—of hydrogen, methane (marsh gas), and ammonia—still envelop giant outer planets such as Jupiter. There, we may come upon clues to the story of our own world's beginning. [*Continued on page 106*]

How We'll Explore the Outermost Planets

[Continued from page 79]

Flying by Saturn within 50,000-mile distance would give awesome, sky-filling view of its unique rings, precisely in plane of its equator (marked by white line).

Through TOPS' eyes we'll look into mysteries that long have tantalized telescope gazers. Here are some highlights of what we'll see.

Jupiter. From perhaps within 150,000 miles of golden Jupiter, less than twice its 88,700-mile diameter, TOPS will view a wondrous sight—the solar system's largest planet and its 12 moons, one bigger than the planet Mercury. Outstanding will be Jupiter's mysterious Great Red Spot—an oval what-is-it some 25,000 miles long, drifting about like a floating island instead of rotating uniformly with the rest of Jupiter. Whether it differs in density may be detectable from the motions of a moon, and of the spacecraft itself, as they pass over it.

In Jupiter's bands of ammonia-crystal clouds, delicate shades of yellow, orange, pink, and pale blue hint the presence of complex organic molecules, as does the brick-red color of Jupiter's Great Spot. Do lightning storms on Jupiter manufacture them? Electric discharges in methane-ammonia mixtures have done so in experiments to demonstrate how organic chemicals essential to life may have originated on earth.

Due for close-up study, too, is the radiation belt around Jupiter—the only planet besides earth known to have one—and the strange torrent of radio noise that radio astronomers detect coming from the planet.

Saturn. Unique to Saturn are its spectacular rings, made up of myriads of orbiting particles of unknown size. TV pictures during a flyby possibly may be able to resolve the largest—though TOPS will give the rings a safely wide berth!

Yellow Saturn's 10 moons—the last discovered as recently as 1966—include the only satellite, Titan, known to have an atmosphere. TOPS may find that others have—and may discover moons unsighted from earth.

Both Saturn (incredibly, less dense than water) and Jupiter emit more energy than they receive from the sun. TOPS' gear may yield clues to where it comes from.

Uranus and Neptune. These greenish near-twins, of almost 30,000-mile diameter, owe their hue to an abundance of methane in their atmospheres. From the earth, both Uranus and Neptune look blank, with no discernible markings whatever. From close up, it could be quite another story. TV views from TOPS may reveal features as unsuspected and astonishing as the moonlike craters that our Mariners found on Mars.

Pluto. While other outer planets are giants, tiny and frigid Pluto is a strange exception—a dwarf with only half the diameter of the earth. Practically nothing else is known about it; a spacecraft will give the first solid information. Whether Pluto has an atmosphere is still to be learned. Until a TOPS looks at it, no one has any idea what it is made of—whether it is rocklike, or what. Mass is uncertain.

Learning Pluto's mass, as could be done by spacecraft tracking during encounter, conceivably could have a dramatic result, suggests the National Academy of Sciences. Its orbit's perturbations might then lead to prediction of another possible planet beyond Pluto—whose discovery would be a major astronomical event.

The Grand Tours will have two precursors—flights by the 525-pound spacecraft Pioneer F and G, slated for launching in 1972 and 1973 respectively. Both will travel only as far as Jupiter, but are expected to furnish information of great importance for the Grand Tours' success.

Launched by Atlas-Centaurs with solid-propellant third stages, the two Pioneers will have flight times, depending on the starting date, of 19 to 32 months. They will be the first craft ever to travel beyond Mars' orbit, and on through the asteroid region, twice to 3.6 times as distant as the earth from the sun—that strange belt of particles ranging from grains of sand up to Texas-size boulders. The Pioneers will collect much information on Jupiter and the interplanetary medium, and demonstrate the crucial gravity-assist maneuver, but without using it for a free ride to another planet.

That will set the stage for the Grand Tours—which the planets' alignment makes possible only every 177 years or so. President Thomas Jefferson missed the preceding opportunity to send spacecraft to explore the outer planets—and NASA is eager not to let another chance in our time slip by.

The Wish Switch in Your Brain

[Continued from page 32]

shown the movie, and asked to speak up when they recognized the target.

The navigators do much more. Each time the projector whirrs and the blurry picture appears on the screen, the results are the same. The computer always shows that the navigators sense the approach of the target at least 10 seconds before they themselves are aware that they are even spotting familiar landmarks.

More in the offing. BAC's Human Factors staff is still evaluating these tests. And making new ones to collect data on the way our brains recognize objects. So far they have drawn no firm conclusions, and they aren't likely to draw any in a hurry.

But the department's psychologists wonder if the wish-switch might not, among other things, speed up the reading of radar scanners. And if certain faster aircraft—not the Concorde, which is completely computer navigated—might not someday carry an extra crew member whose sole job would be to make visual observations of landmarks, with or without wish-switch assistance. BAC psychologists see no limits to the possible uses of wish-switches. They might speed some factory processes, might even make boiler-room work more precise.

Grey Walter's interest in experiments in which BAC's navigators assist is in the "E" (for "expectancy") current his computer shows that the brain builds up during the run to the target. Long ago he related the increase in this current to mental stress, a condition he is also studying.

His main work, however, is mapping our brains completely, determining not only precisely which sector gives off CNV charges, but also which other sectors produce other charges, and why. Complete knowledge of this spatial distribution, he believes, may someday lead to the wholesale curing of brain disorders.

More spectacular even than this, Dr. Grey Walter thinks that such research as his will someday help neurologists to prescribe drugs that will alter our intellects and/or our intelligence. Drugs to raise our IQs. Drugs to make us more artistic. To improve our technical capabilities. To make us mathematical geniuses. To make us great leaders (or, perhaps, complacent followers?).

Meanwhile, because funds are so limited, research creeps on. Research on electrical bursts too feeble to make the smallest flashlight bulb flicker. But still capable of lighting up the world.

MARCH 1971 60 CENTS

Popular Science

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Medical Spin-Offs from the Space Program
By WERNHER von BRAUN

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A multi-g human centrifuge performs an operation too delicate for surgery—and an emergency rocket-control idea yields a wheelchair you can steer with your eyes

Medical Spin-Offs from the Space Program

By DR. WERNHER von BRAUN
NASA Deputy Associate Administrator
PS Consulting Editor on Space

Sight-controlled wheelchair is tried out by Dr. von Braun. Facing straight ahead, he steers battery-powered chair in desired direction just by turning his eyes sideward. Learning how to run it took him only 10 seconds.

For the first time in medical history, in late 1968, an astronaut-testing human centrifuge was drafted to save a life by moving a bullet fragment in a holdup victim's brain. The dramatic case was just one instance of new medical wonders that have come about as dividends, or "spin-offs," from our space program.

All of us benefit by these medical spin-offs from space. They enter into everyday life at home, office, and factory, as well as at the doctor's office and the hospital. Too numerous even to list here completely, they speed recovery from ills, allay suffering, and enable the handicapped to live a useful and enjoyable life. Here are just a few examples:

The life-saving centrifuge

Shot in the head by a robber, Joseph Barrios, 63, of Morgan Hill, Calif., was rushed to a San Jose hospital. Finding the bullet had shattered, surgeons extracted all but one fragment, which they dared not try to reach. X-rays showed it was in a critical region of Barrios' brain—and was gradually shifting, imminently threatening to reach a fatal spot.

The only hope was somehow to move the fragment out of harm's way—and the hospital enlisted the aid of NASA's nearby Ames Research Center. Ames had a human centrifuge, a whirling cockpit in which astronauts undergo many-times-normal gravity for space tests and research. With a duplicate of the bullet fragment and a model of gelatin, which simulates the consistency of the human brain, Ames doctors rehearsed an emergency plan to move the fragment with the centrifuge.

Brought to Ames, Barrios was carefully positioned in the cockpit, helmeted and wearing astronaut-style gear to telemeter his pulse rate, breathing rate, and electrocardiograms. As the centrifuge spun, a TV camera eyed his face, and instruments monitored his condition. He whirled for nearly a half minute, at a force up to six g's—which in effect multiplied his weight six times—and was able to smile and chat with the doctors when he emerged. The centrifuge "operation" was a success, later X-rays showed. The bullet fragment had been shifted to a region where it would be harmless, and embedded and immobilized there.

Eyes steer a wheelchair

For a paralysis-stricken person who cannot use a standard wheelchair, NASA has come forth with a mechanized chair controlled by a "sight switch," originally born of a space need. During my years at the Marshall Space Flight Center we were looking for a way to aid astronauts in an emergency if high g forces rendered them unable to move their arms or legs. Suppose, say,

an out-of-control rocket vehicle spun or gyrated so wildly as to pin them helplessly to their couches; how could they cut off the engine? One clever answer to the problem was a sight switch built into a pair of eyeglasses.

A tiny lamp on each side of the frame bounces an invisible beam of infrared light off your eye and back into a photocell, which senses the difference between the white of the eye and the darker pupil. Turn your eyes, and the reduced reflection—as the pupil crosses the light-beam's path—activates an electric switch.

Plainly this switch can be applied, too, to brighten the life of a victim of paralysis. It can control room lights, a thermostat, or a TV set, or turn the pages of a book. Just as well, it can start and stop a motorized wheelchair—and steer it, too. You look to the left once to start, again to stop, again to reverse. You look to the right to turn right; again, to turn left.

How simple it is to use an eye-operated wheelchair, I saw for myself, when a battery-powered electric version was built and tried out at the Marshall center. It took me just 10 seconds to learn to run it. A beginner's only likely mistake, I found, is to glance out of the corner of his eye at the instructor beside him. This operates the eye switch and evokes an unexpected change in the chair's motion. To view anything to one side without doing so, you turn your whole head.

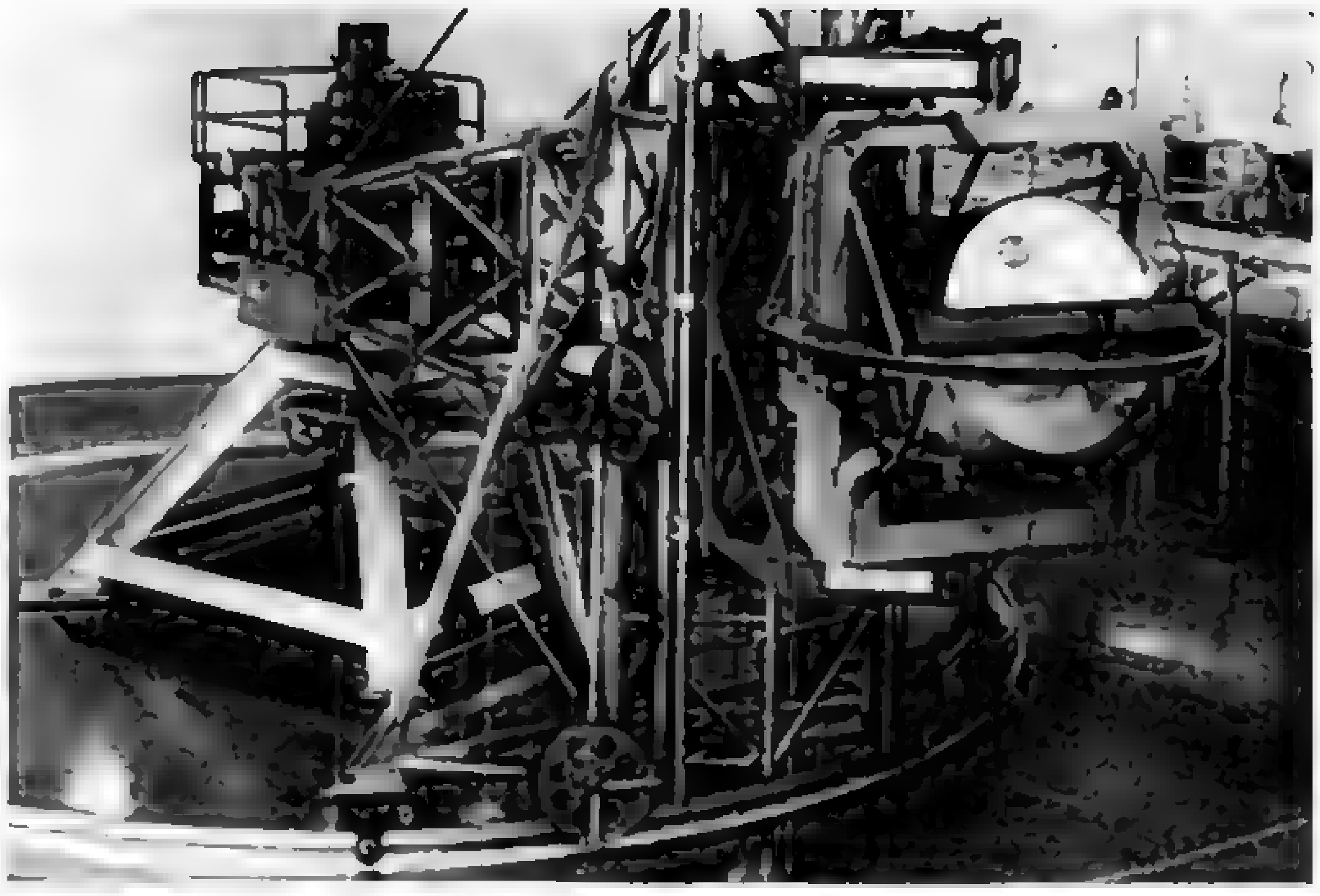
A car that walks

From a proposed design for a lunar crawler has come a walking car—especially suited for crippled children, who take delight in operating it. Wheelless, it travels on eight legs—powered by a battery and electric motors—and has two speeds in forward and in reverse. Its novel method of locomotion enables it to ride over curbs (as pictured on the next page) and even up stairs. The rider guides it simply by pushing an upright control stick in the desired direction.

To the moon and Mars, medicine owes other advances, some of which may touch your life more closely:

- If that X-ray of your innards isn't as clear as your doctor needs for a sure diagnosis, it can now be made more revealing. "Computer enhancement," a technique developed to bring out obscure details in photos of the moon and Mars (by enhancing contrasts, for example) has lately been applied with striking success to improving medical X-rays. (See photos, next page.)
- Measuring the oxygen you consume during exercise formerly required you to wear a nose clip and breathe through a mouthpiece. Now you breathe freely in a modified astronaut's helmet, sealed at the neck, with an air inlet on one side and an outlet to a suction pump and air analyzer on the other. Youngsters enjoy donning the "space helmet" for a clinical test.
- Because lubricants evaporate in a vacuum, NASA has sought to reduce friction in metal-to-metal bearings for lunar vehicles. From its Lewis Research Center at Cleveland have come antifriction bearings of new titanium alloys, with a hexagonal crystal structure instead of the usual cubic one. If current trials at Cornell Medical Center confirm that these alloys can safely be implanted in living tissue, they promise artificial hip joints of greatly improved mobility and comfort, to replace damaged human ones.
- Already proven compatible with fluids and tissues of the human body is a high-purity, high-strength form of carbon developed in NASA experiments requiring instruments to be implanted in animals' internal organs. Medical use of this new "biocarbon" for artificial heart valves and other human implants is now foreseen.
- Learning to walk on artificial legs is made easier

Continued



In medical drama below, this human centrifuge saves a man endangered by bullet fragment in his brain, beyond reach of surgeons.

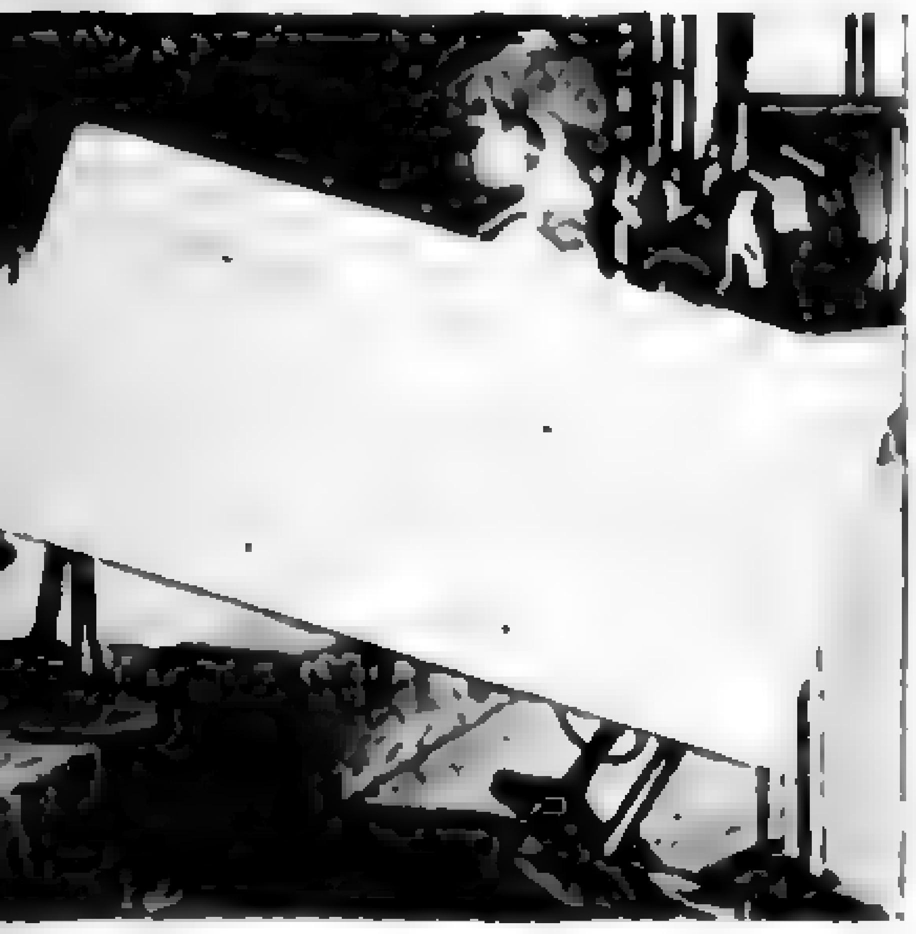
Holdup victim Joseph Barrios is readied in centrifuge for use of its six-g force to move fragment from perilous area to safe one.

Placed so force will tug in right direction, Barrios (in helmet) gets final instructions. Then the centrifuge is set whirling.

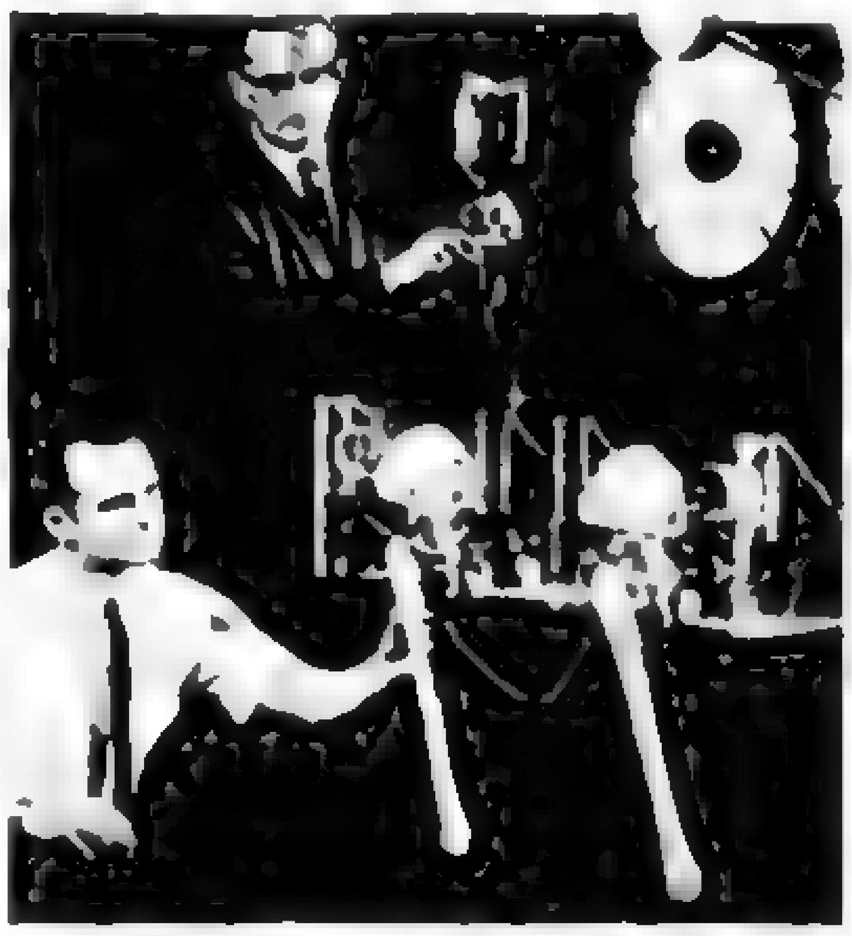
Brief ride is watched by doctors at TV screen of monitoring console. It succeeds in moving bullet fragment out of harm's way.

New spray-on electrodes (inset above), applicable as shown in about three minutes, enable a heart-attack patient's symptoms to be radioed ahead to hospital by ambulance rushing him there. Doctors will then be ready with immediate aid when he arrives.

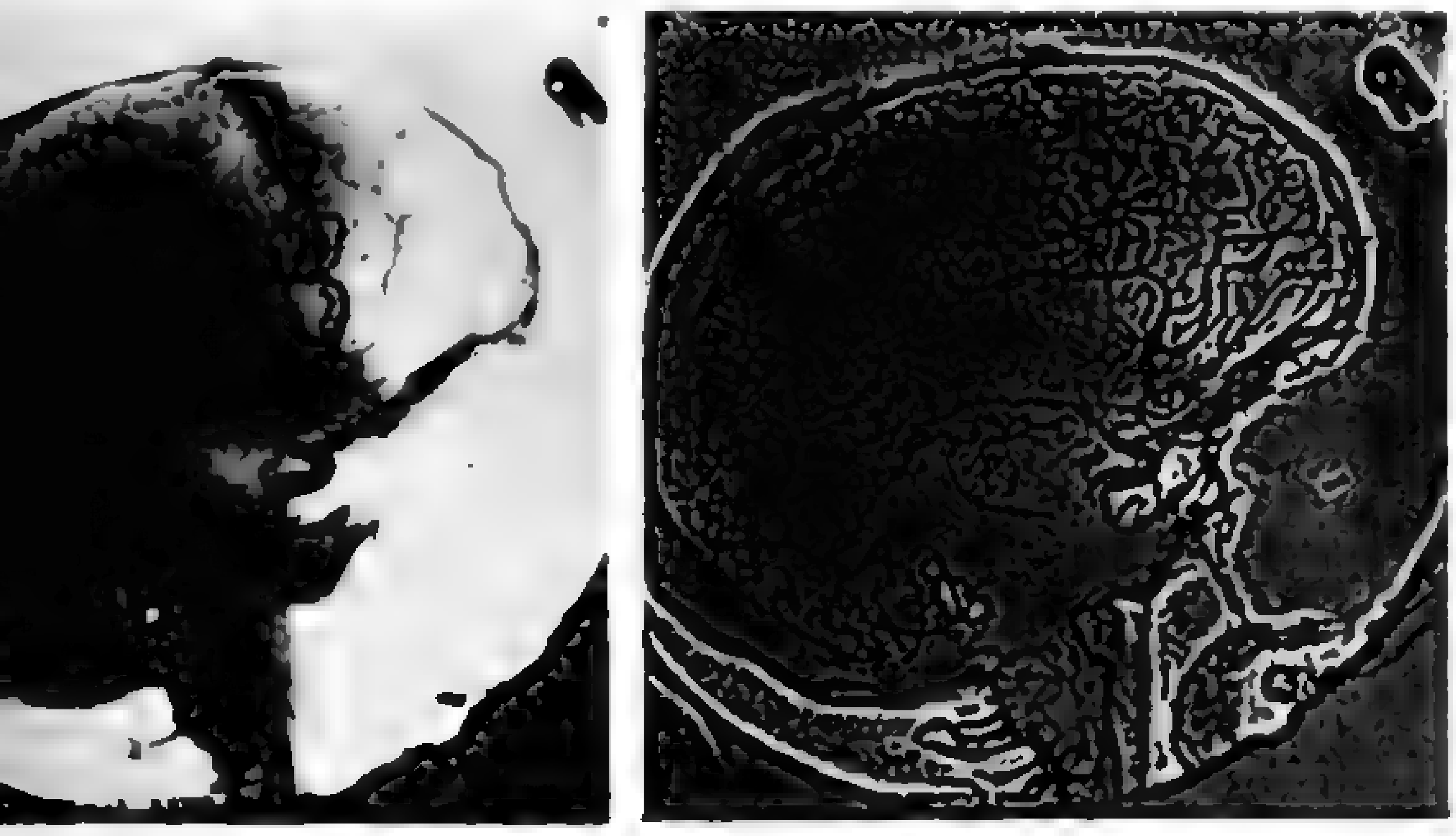
Remote monitoring is becoming major aid for intensive care. Baby recovering from surgery, left, wears radio transmitter that sounds alarm and brings nurse on the double if sensor detects breathing difficulty.



Eight-legged car, patterned after proposed moon vehicle, gives crippled child an enjoyable way to get around. It walks over curbs and up stairs.



Low-friction bearing alloy from space lab shows promise for repairing human hip, in this hip-joint simulator at NASA's Lewis Research Center.



X-rays gain clarity by technique that improved photos of moon and Mars. Frontal blood vessels of head, obscure in X-ray at left, stand out strikingly in a "computer-enhanced" version at right.

by support with a weight-reducing sling, similar to a device that trains astronauts to walk on the moon, where gravity's force is one-sixth of that on earth.

Electrical monitoring is proving a magic gift to medicine as well as to the space program.

Astronauts wear harnesses of electric wires with skin contacts, so ground observers can check their physical condition in flight. Early hookups were delicate; their metal-disk contacts sometimes came loose or made imperfect connections. Now NASA has developed "spray-on electrodes," quickly and firmly attached to your skin by spraying a fast-drying conductive mixture over a wire's end. What results is a thin, flexible disk-shaped contact able to withstand vigorous exercise, though easily removable at will. This practical way to wire you up offers a variety of medical uses.

To picture one likely application in the not-so-distant future, suppose you have a heart condition that calls for careful watching. Wearing spray-on electrodes, you can go about your daily business, while your electrocardiograms are taken by a tape recorder no larger than a pack of cigarettes, carried in your pocket. At the end of a week you put the tape in an envelope and mail it to a Central Medical Computer Office. There a computer compares it with a record of your heart's normal performance, already on file. If the computer detects a significant departure from your "norm," your doctor will be notified, and you'll be advised to make an early appointment to see him.

While this plan is not yet operational, other important medical uses of spray-on electrodes already are.

The next ambulance that passes you, siren screaming, may be speeding a man with a heart attack to the hospital. Possibly too, even as it weaves through traffic, it may be radioing ahead the man's electrocardiograms to the emergency ward, via spray-on electrodes. By the time he arrives there, doctors will know the nature and severity of his attack and can give instant aid. First introduced in Los Angeles, the radio-ambulance technique looks ready for widespread adoption.

Boon to intensive care

Perhaps the most important contribution of NASA medical spin-offs is in the field of intensive care.

Electrocardiograms, other cardiac information, and data such as breathing rate and fever temperature, picked off from the patient's body with spray-on electrodes and various sensors, are transmitted by wire or radio to a central computer. The computer's memory is preloaded with the data normal for the patient and any variations in the incoming data are detected by comparison. Alerting the nurse, it gives her a simple print-out of the patient's name and room number and the nature of the abnormal condition.

Thousands of Americans are now alive because of these new monitoring techniques, which are becoming more and more widely used from coast to coast. Some 100,000 more lives could be saved yearly in the U.S. alone, it has been estimated, if we could make the most of our hospitals' intensive-care wards.

Automated monitoring of patients offers an answer to what has been the principal problem—the legions of attendants that have been needed to keep a 24-hour vigil over other legions of intensive-care patients. Thus it holds the hope of slashing the high cost of intensive care to patients—and of easing the plight of the many hospitals that lack enough personnel, or the funds to pay them. Without computerized intensive care, our Apollo/Saturn space vehicles with their legions of subsystems would never have carried our astronauts to the moon and back.

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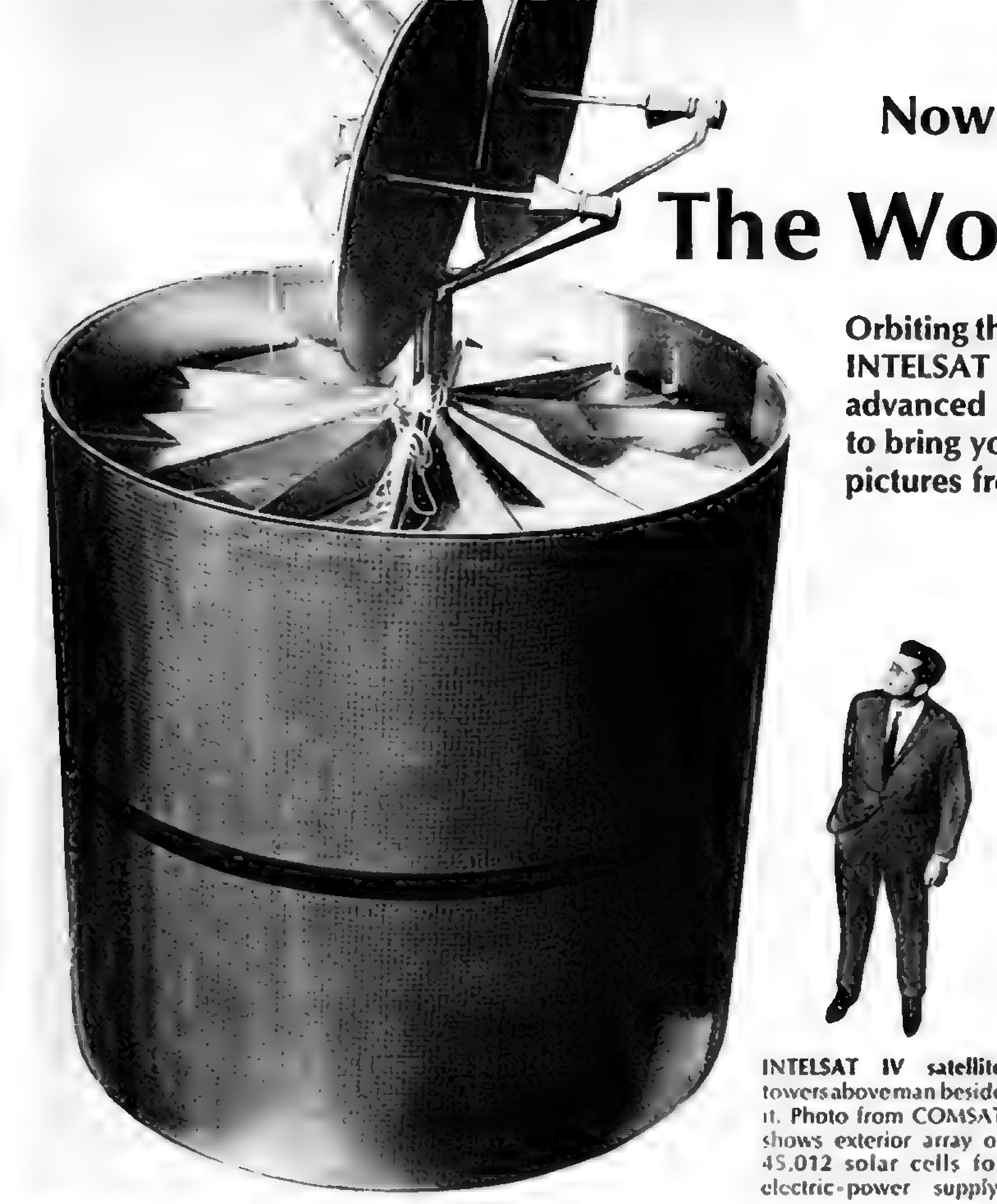
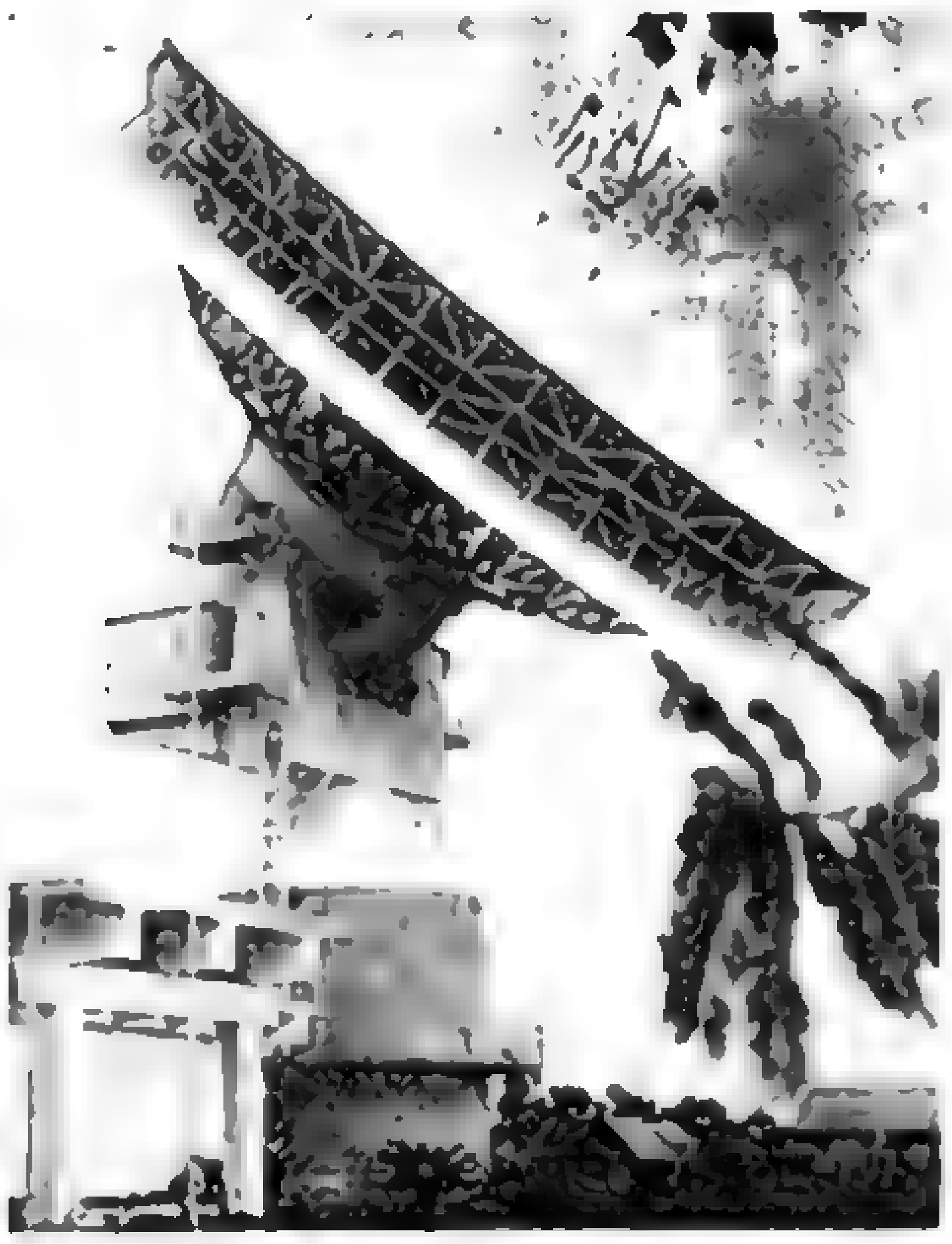
Orbiting the first of eight huge INTELSAT IVs inaugurates an advanced new communications system to bring you voices and television pictures from across the sea



INTELSAT IV satellite towers above man beside it. Photo from COMSAT shows exterior array of 45,012 solar cells for electric-power supply.



Ground stations, like this new one for Indonesia at Djatiluhur, tie trans-ocean satellite-relay system to land lines. Bowl-shaped antenna, measuring 90 feet in diameter, is decked with flags at its completion.

By
DR. WERNHER von BRAUN
NASA Deputy Associate Administrator
PS Consulting Editor on Space

A $29½-million telephone-and-TV satellite, almost two stories tall and weighing a ton and a half at launch, has newly been put at your service. Rocketed from Cape Kennedy last January, it now hangs 22,300 miles above the Atlantic, permanently stationed over the equator at 24½ degrees West Longitude, where it began operating in March.

This huge drum-shaped spacecraft, and seven more like it, will make up a new INTELSAT IV (fourth-generation) system of commercial communications satellites to relay voices, pictures, and data across the seas.

Most "talkative" commercial communications satellite ever built, the first of the INTELSAT IVs transmits 3,000 to 9,000 transatlantic phone conversations simultaneously—or 12 color TV programs, or a combination of telephone, TV, and other traffic, according to ground command. This compares with a puny 750 telephone circuits for the fifth and most sophisticated transatlantic cable that started service in 1970.

The new orbital telephone exchanges will more than quadruple the total capacity of all previous communications channels (including both satellites and cables) across the Atlantic, Pacific, and Indian Oceans. They will truly establish what Arthur Clarke, prophetic writer on space, has called "mankind's first nervous system," which will "link together the whole human race."

What the satellites do. Although you may seldom pick up a phone to call London or Tokyo—so far—we all do enjoy the new marvel of seeing by satellite. When U.S. watchers were treated to a spectacularly close-up TV view of Apollo 14's home-from-the-moon splashdown in mid-Pacific last February, it was a dramatic example of a satellite-relayed news event that would have been impossible to bring to your home screen only a few years ago.

Communications satellites act as relay stations for the beams of microwaves that can carry either a multitude of phone circuits or the sheaf of complex signals required for TV. Unlike longer radio waves, which follow the curvature of the earth, microwaves travel only in straight lines-of-sight. So, to relay microwaves across the sea, a satellite has a receiver to which a ground station beams them up, an amplifier to boost their strength, and a transmitter to return them to a ground station on another continent.

In principle, this is much the same way that relay towers carry microwaves long distances over land. However, the land towers' limited height usually requires spacing them only

Talkative Satellite

Latest INTELSAT satellite can aim "spot beams" at selected areas (inside the small rings), or take in most of hemisphere with "earth beam," as COMSAT artist illustrates at right.

50 to 60 miles apart to keep them within line-of-sight of each other. In contrast, a single satellite, equivalent to a microwave-relay tower hundreds or thousands of miles high, suffices to relay the signals across an ocean.

INTELSAT IV is the most advanced communications-satellite system yet devised for this purpose. What its new satellites will do for you can best be seen by comparison with what has gone before.

Forerunners of INTELSAT IV. Talking and seeing via satellite has come a long way in just a few years. No longer ago than 1962, AT&T's experimental Telstar 1 brought us the first crude telecast from Europe. The signals lasted only 22 minutes before the low-flying satellite sailed out of range of the ground stations in Maine and in France.

With enough satellites swooping past, it would be possible to maintain communications by switching from one to another as they successively came into view. Indeed, this plan has actually been applied by the Soviet Union—which, beginning in 1965, has launched at least 16 Molniya satellites for communications over its vast land expanse from Moscow to Vladivostok.

The world's first "stationary" satellite, NASA's experimental Syncom 3, demonstrated in 1964 an alternate scheme that Americans have preferred ever since. Launched into 22,300-mile-high orbit over the equator, it kept pace exactly with the earth's rotation, so that it apparently hung motionless in the sky. From its lofty vantage point above the Pacific, it successfully relayed the televised 1964 Olympic Games from Japan to the U.S.

Likewise from such a "synchronous" orbit (and the 22,300-mile height it requires), Early Bird (later renamed INTELSAT I) opened the first commercial communications-satellite link across the Atlantic in 1965.

The generations of INTELSATs. Canary Bird and Lani Bird were the popular nicknames for improved second-generation, INTELSAT II satellites, of which three were successfully orbited over the Atlantic and Pacific in 1967. Third-generation INTELSAT IIIs, of which five were put in service over the Atlantic, Pacific, and Indian Oceans in 1968-1970, provided the first worldwide system.

A 1968 description of the INTELSAT III system declared: "Direct-dial telephone service between the general public in Europe and the United States via INTELSAT III is expected by 1970, and at significantly lowered rates." Punctually, the prediction was fulfilled in March, 1970, by the opening of the world's first major intercontinental dialing system between New York and London—with the former rate reduced by more than one-third.

From little 85-pound Early Bird to the 322-pound INTELSAT IIIs, with an increase in capacity from 240 to 1,200 telephone circuits per satellite, was a big advance. But what communications specialists called a "talking explosion" continued to demand expanded facilities.

By 1969, 15,000 U.S.-Europe phone calls daily were taxing satellites and cables, and callers had to expect a 20-to-30-minute wait to get a connection. AT&T was then using 468 satellite circuits around the world and needed 175 more, it told the Federal Communications Commission.

Experiments were indicating, too, that more satellite capacity could provide novel and valuable services. From a remote oil field, prospecting data could be rushed via satellite to a computer for analysis, a trial showed. Computers were able to "talk" to each other across an ocean by satellite—suggesting that satellite-relayed business data could provide a firm's overseas branches with records as complete as its home office's.

That's the story behind the new INTELSAT IV system.

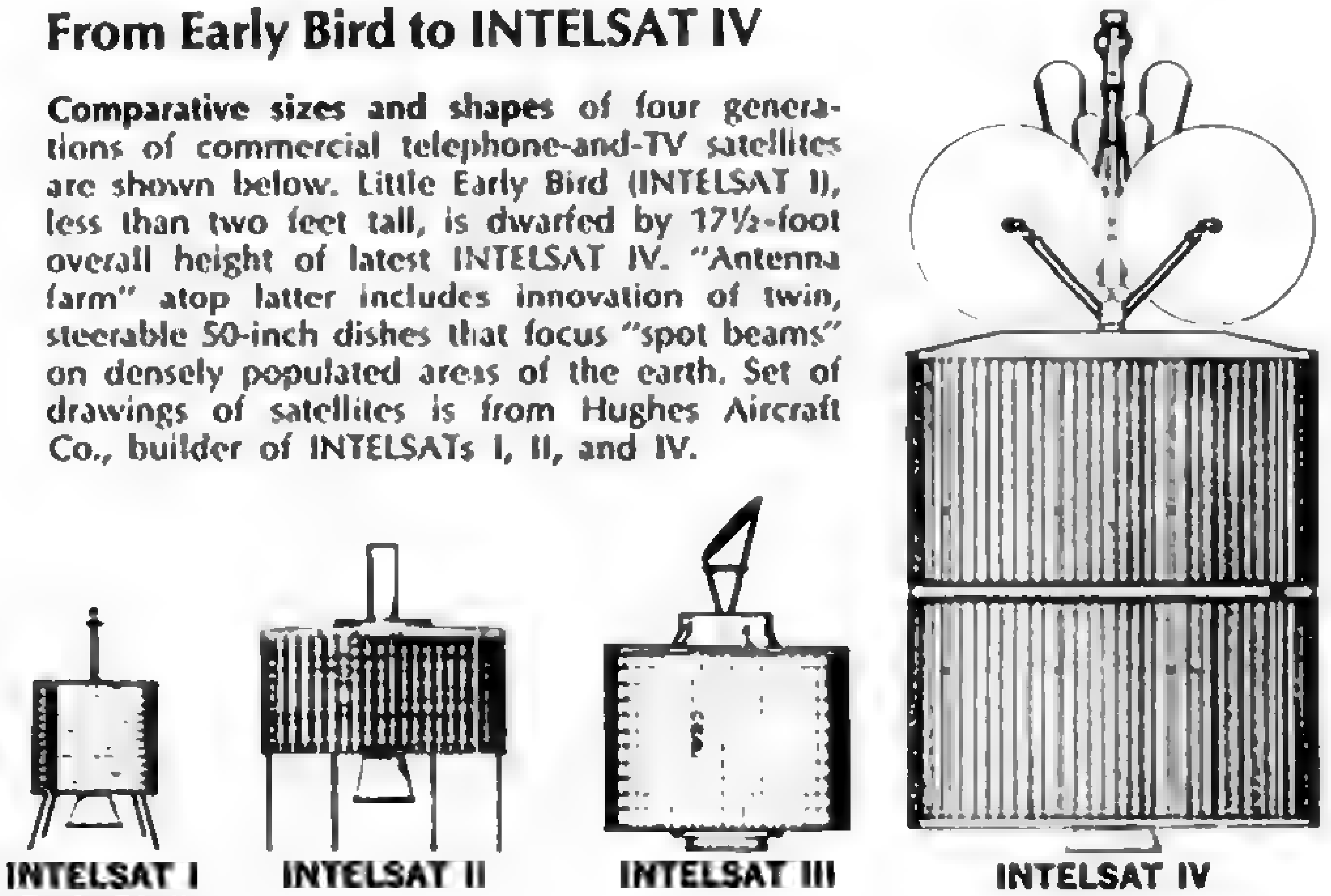
Features of new design. The outside of the INTELSAT IV satellite glitters with a mosaic of more than 45,000 glass-covered solar cells. They furnish 569 watts of electric power to run 12 receiver-transmitter systems and other gear (and to recharge batteries that take over when the satellite occasionally passes through the earth's shadow).

The satellite's base contains a rocket motor that imparts the final kick to attain synchronous orbit, and about 1,400 pounds of solid fuel for it. This firing reduces the weight of

[Continued on page 138]

From Early Bird to INTELSAT IV

Comparative sizes and shapes of four generations of commercial telephone-and-TV satellites are shown below. Little Early Bird (INTELSAT I), less than two feet tall, is dwarfed by 17½-foot overall height of latest INTELSAT IV. "Antenna farm" atop latter includes innovation of twin, steerable 50-inch dishes that focus "spot beams" on densely populated areas of the earth. Set of drawings of satellites is from Hughes Aircraft Co., builder of INTELSATs I, II, and IV.



At Your Service: The World's Most Talkative Satellite

[Continued from page 57]

the satellite in orbit to a little more than 1,500 pounds.

Satellite aims pinpoint beams. New on the INTELSAT IV satellite are steerable "spot-beam" antennas, besides wide-angle ones like those of its predecessors.

The 17-degree field of its wide-angle "transmit" and "receive" antennas covers the earth's whole visible disk from 22,300-mile altitude—about two-thirds of a hemisphere. If all users of the new central-Atlantic satellite were scattered at random over the vast area of this "earth beam," only 3,000 simultaneous telephone circuits could be provided.

However, most users are bunched in areas along the U.S. east coast and in western Europe. These densely populated regions will be served by needle-sharp "spot beams" from twin dish-shaped transmitting antennas of 50-inch diameter, steerable in 0.1-degree steps by ground command. The spot beams, only about 4½ degrees wide, cover a region on the ground of 1,000 to 1,500 miles in diameter. With maximum use of these beams the satellite attains its peak of 9,000 simultaneous telephone circuits. Under typical operating conditions, spot-beam and earth-beam service will be mixed for an average of some 5,000 phone circuits.

Orbiting an INTELSAT IV satellite takes a huskier launch vehicle than served for earlier INTELSATs. The newly launched INTELSAT IV was boosted by a 100-foot-tall Atlas-Centaur, the same rocket combination that served to launch all our Surveyor spacecraft to the moon and our last Mariner spacecraft to Mars.

Launching an INTELSAT IV. Since a launch from Cape Kennedy's latitude puts a spacecraft in an orbit inclined to the equator, tricky "dog-leg" maneuvering is required to alter its course to the equatorial orbit of a synchronous satellite.

In last January's launch the Atlas-Centaur successively put the INTELSAT IV satellite in an elliptical "parking" orbit and then in a higher-reaching elliptical "transfer" orbit, more nearly aligned with the equator. At the 22,300-mile-high point, firing the satellite's own engine nailed it at synchronous altitude, and completed shifting its orbit to the equatorial plane. The satellite was then over the Pacific. From there, it was allowed to drift slowly around the equator for more than a month to its final station above the Atlantic.

Since then, the satellite's six hydrazine-fueled thrusters have come into play to keep it from drifting away from its wanted stationary position. The hydrazine supply aboard the satellite is sufficient to keep it on station for an expected useful life of seven years.

To stabilize the satellite like a gyroscope, its thrusters also served to set it spinning at a rate of about one revolution a second. Its "antenna farm," mounted on a platform that counter-rotates at precisely the same rate, stays pointed in a fixed direction at the earth.

Two more INTELSAT IVs, for the Pacific and Indian Oceans, are expected to be launched this year.

By far a record for commercial satellites, the INTELSAT IVs' relaying capacity is matched only by one experimental military version. This is the U.S. Defense Department's Tactical Communications Satellite of 1969, whose slightly greater 10,000-telephone-channel capacity is not designed for use by the public. In contrast, INTELSATs literally belong to the world.

Their owner, a group called the International Telecommunications Satellite Consortium (INTELSAT), now represents 77 nations. Its manager and U.S. member is the Communications Satellite Corp. (COMSAT) of Washington, D.C. Its INTELSAT IV satellites are being built by Hughes Aircraft Co., with subcontractors in many countries.

For large and technically advanced member nations of INTELSAT, the new system will be a massive and welcome addition to marginal facilities for global communication. For remote countries such as Senegal and Zambia, it will provide their first round-the-clock communication's window to the rest of the world.

Costliest item: the launch. An INTELSAT IV satellite costs about \$13½ million, before launching. With NASA's \$16-million charge for launching it, the price tag totals some \$29½ million per satellite—which INTELSAT expects to be a handsomely profitable investment.

Looking ahead, I foresee that we shall reach a point within another 20 years where space activities will earn more than they cost. The earnings will come from such bread-and-butter programs as communications satellites, which should prove a space "gold mine." By the year 2000, I am sure, we'll wonder how people ever got along without them.

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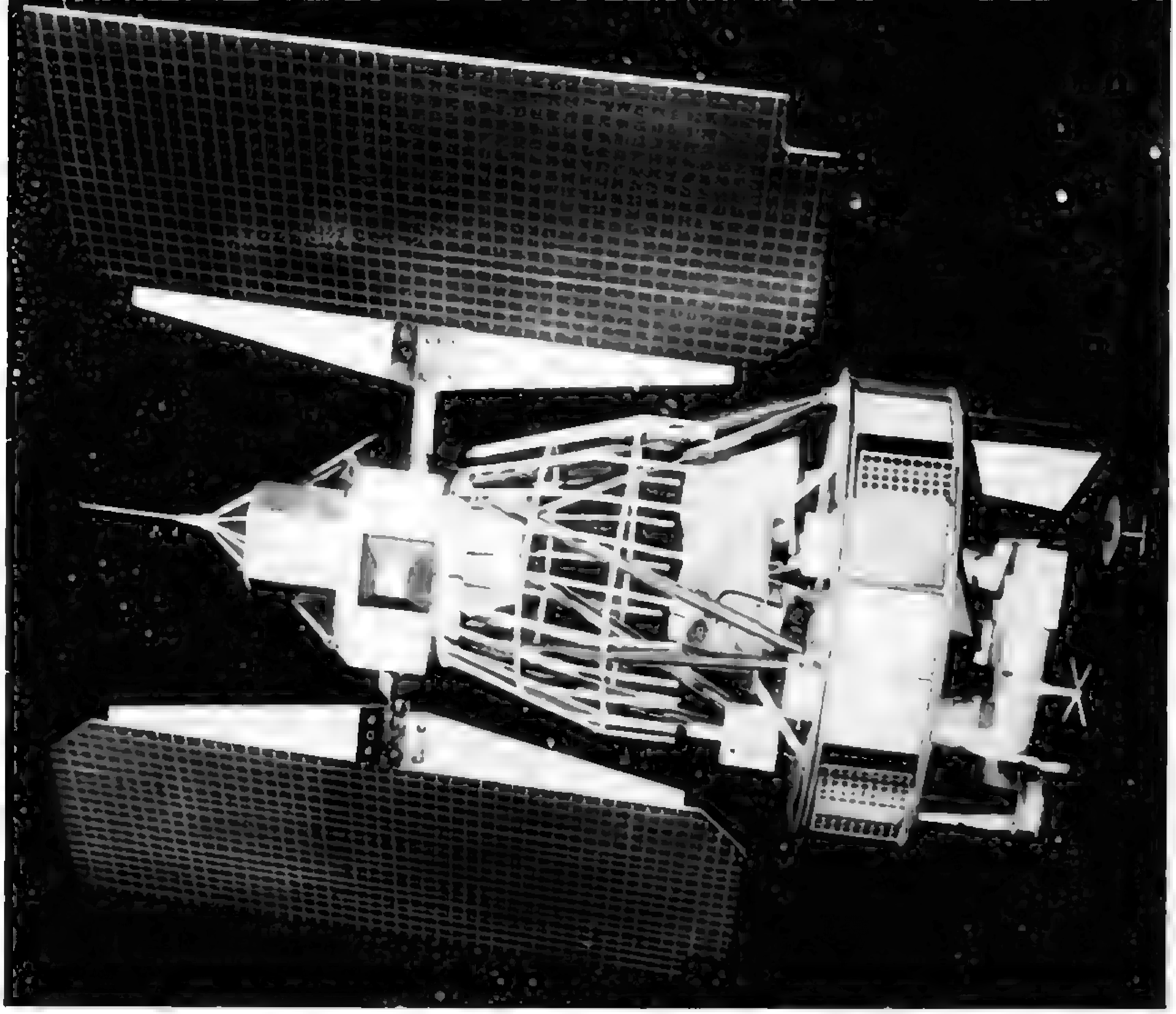
How images relayed by new satellite series will benefit you

By DR. WERNHER von BRAUN
NASA Deputy Associate Administrator
PS Consulting Editor on Space



Bristling with antennas to beam TV images and data to earth, ERTS-A spacecraft shown in this artist's conception will orbit earth next year, beginning a survey of our resources.

Saving Earth's Resources with Photos from Space

In late March next year a Delta rocket is scheduled to lift from a launch pad at California's Western Test Range. Roaring skyward, it will place a 1,788-pound payload into a special "midmorning" near-polar orbit 565 miles above the earth.

From this orbit, sophisticated multispectral sensing devices in the first Earth Resources Technology Satellite, ERTS-A, will probe the vast expanses of land and water beneath it. TV images and other data will be transmitted to ground stations in Alaska, Maryland, and Texas, and converted into photographs. ERTS-A will operate for one year, then ERTS-B—equipped with more complex sensors—will take over from a similar orbit. As scientists determine how the images and data streaming from these experimental satellites can be processed and used most effectively, they will plan progressively more complex ERTS spacecraft for the '70s.

What can earth photos from space tell us? Striking and incredibly detailed photographs made during manned Gemini and Apollo orbital missions (next page) have already provided important information on earth resources, demonstrating the value of space-borne platforms for earth surveys.

With such photos, experts can spot both air and water pollution, chart urban growth patterns, and map the constantly changing surface of the planet accurately and rapidly. (Nearly one million aerial photographs are required to form a photomosaic of the U.S., whereas just 400 satellite pictures can cover the same area.) The nation's limited natural resources of water, minerals, oil, fish, and agricultural crops can be surveyed and managed more effectively by planners. Foresters, farmers, fishermen, and others will eventually benefit directly from data provided by ERTS spacecraft.

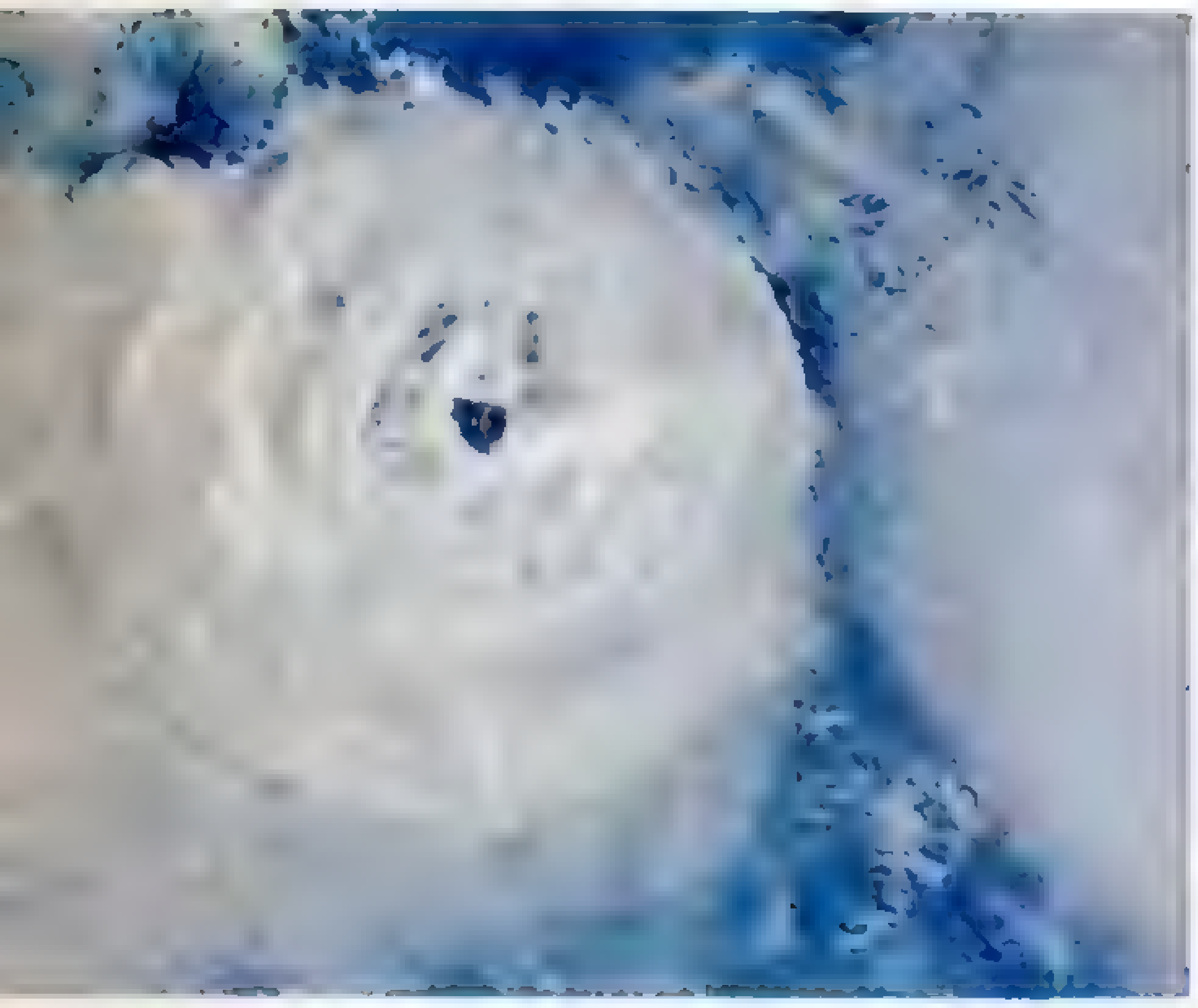
ERTS will pioneer another concept of great potential. Numerous data-collection platforms equipped with temperature, humidity, wind-speed and other instruments will be set up throughout the U.S. and its coastal waters. Data will be radioed up to ERTS, which can then beam it to central receiving sites on the ground for use by meteorologists. Sensors located in streams and rivers could beam data to ERTS, providing advance warning of floods.

Many additional uses of the ground-to-ERTS data-collection system have been suggested. One example: Tiltmeters—a type of precision level gauge—could be installed in the craters of some 220 active or dormant volcanoes. Since volcanic eruptions are invariably preceded by a volcano's subterranean "magma chamber" filling up, a passing satellite

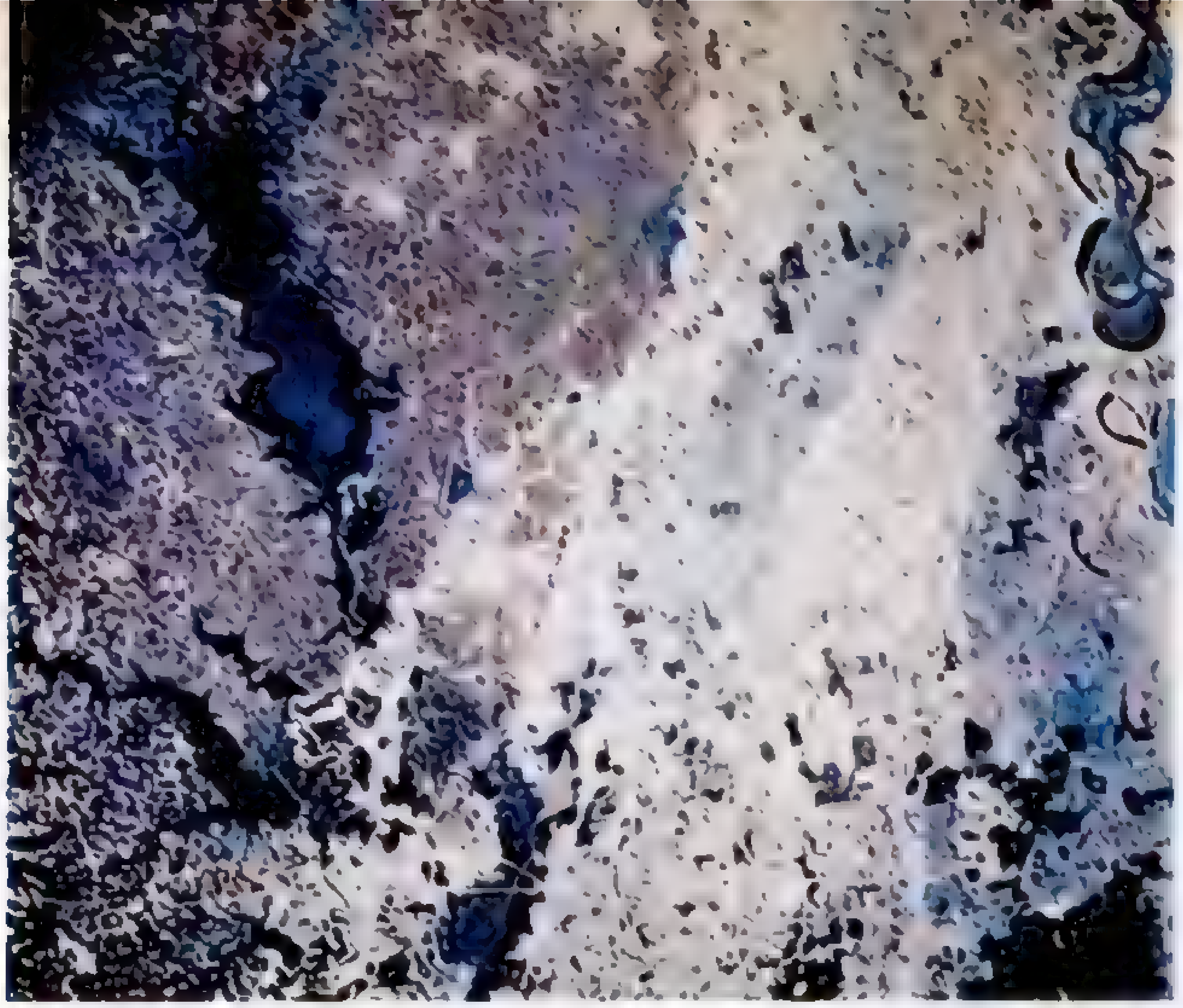
[*Text continued on page 121*]

The promise of surveys from space: Turn page for spectacular astronaut-made photos ▶

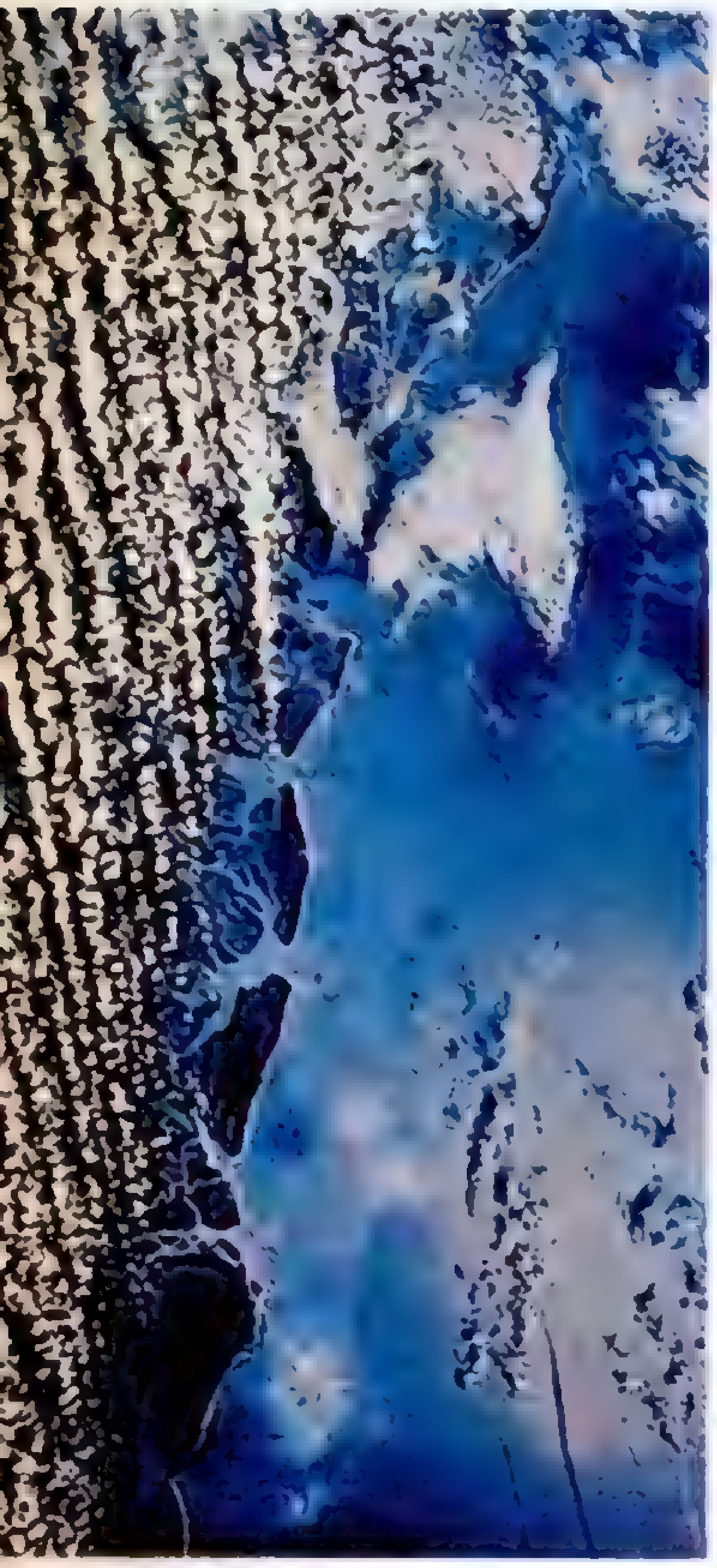
Earth's awesome sights recorded in manned-spaceflight photos . . .



Circular shape of huge thunderstorm cell over South America indicates its slow movement. High-quality photos from ERTS series will benefit meteorologists.



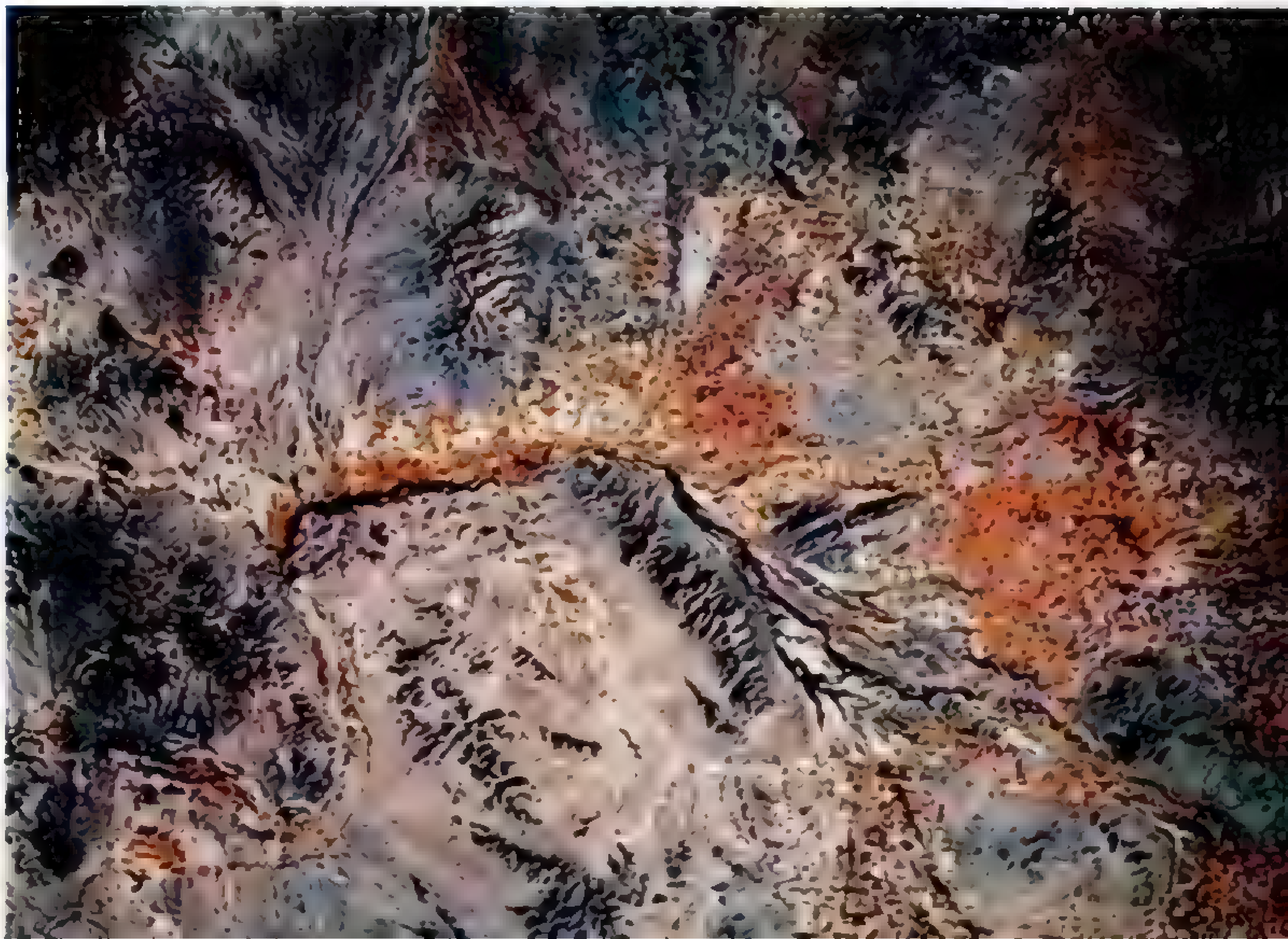
Color infrared photo of Vicksburg, Miss., area shows potential of satellites in forestry management. Dark blotches in light area (once a flood plain) are uncut timber patches. Colors show light-reflectance variation.



Continental slope into Atlantic and river sediment are visible near shoreline between Brunswick and Savannah, Ga. Among uses for such photos: mapping features of coasts and inland lakes, forecasting floods, locating fishing areas.

Plumes of smoke from forest fires drift over northern Australia in this color photo taken from Apollo 7. Infrared sensors in satellites detect fires easily, and can be used to determine extent of burning areas, since they can "see" through the smoke.

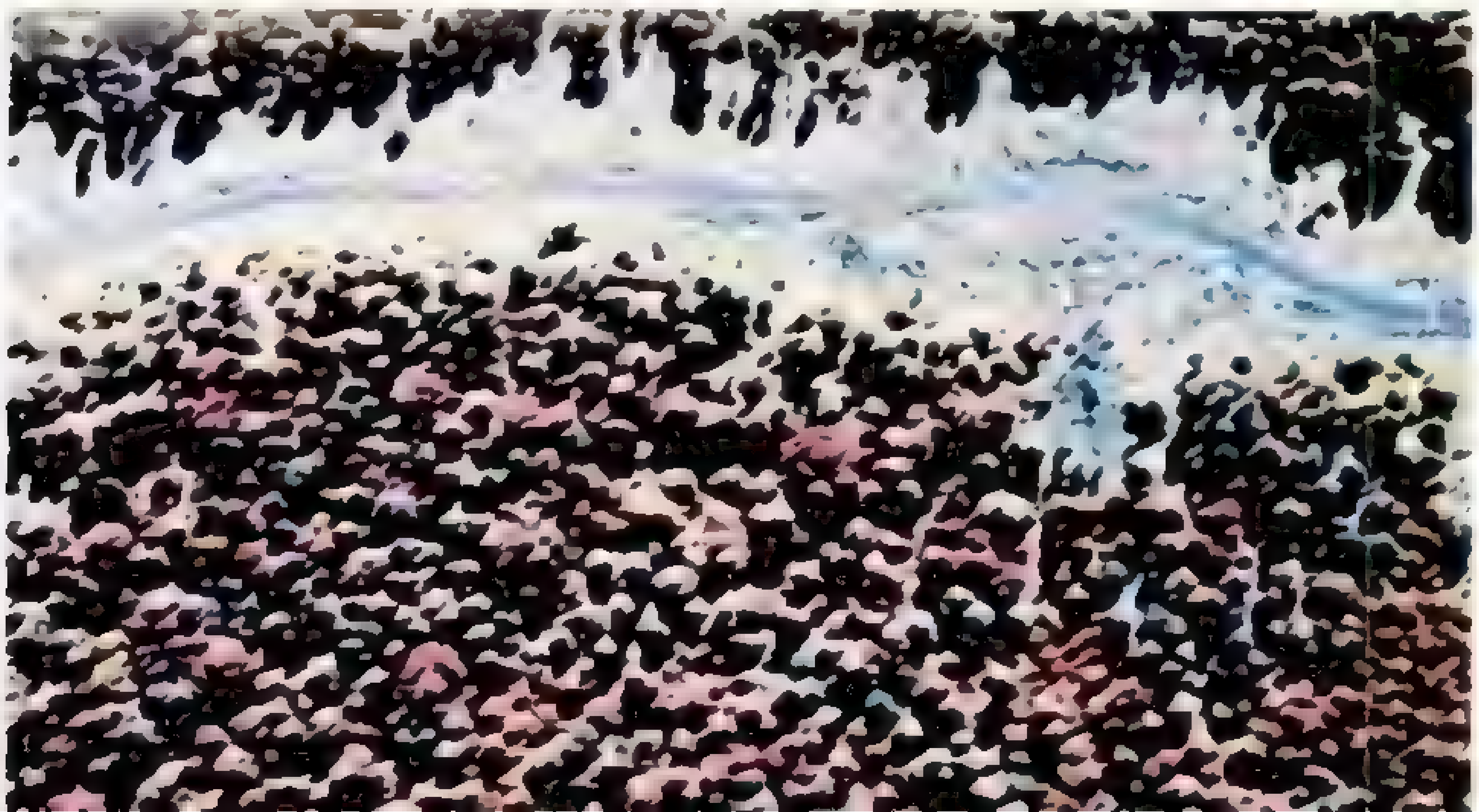
Cultivated land near Phoenix, Ariz., (right of center) registers as red squares on color infrared film. Urban growth, agricultural activity, and grazing-land management are a few areas of national land-use studies aided by analysis of space photos.



Political boundary stands out sharply in this color infrared shot of California's Imperial Valley and Mexico. Tiles used to drain salts in U.S. irrigation water create lush farmlands. In Mexico (bottom of picture), soil salinity limits vegetation.

Clouds of sediment from shoals on Cape Hatteras, N. C., drift into the Atlantic. Monitoring the ocean's surface with satellites will help pinpoint oil and chemical slicks, which now threaten oxygen-generating plankton.

Insect-infested trees in Oregon appear blue-green in aerial photo, while healthy trees are red or pink. Why? Unhealthy leaf cells reflect fewer infrared rays, and the color infrared film sees what human eyes can't.



Saving Earth's Resources with Photos from Space

[*Continued from page 77*]

could relay changes in tiltmeter readings to a ground computer; endangered regions could then be alerted.

ERTS spacecraft will utilize the flight-proven Nimbus satellite design, modified to perform the earth-resources mission. The spacecraft will be attitude-stabilized by a control system that receives pitch and roll commands from horizon scanners and yaw control by means of a gyro compass. Earth-pointing accuracy is 0.7 degrees or better. Solar panels will provide about 1,000 watts of electrical power.

The orbit has been designed so that during one-half of each orbit, it will be midmorning at every point on the earth's surface scanned by the sensors. Sun angles and illumination are thus standardized, and cloud cover, which frequently forms only in the afternoon, is minimized. ERTS sensors will "view" a given area of the earth's surface under the same lighting conditions every eighteenth day.

A standard sun angle is important to help establish so-called "ground truth" areas. The angle at which sunlight falls on a given area can make a considerable difference in the appearance of a location in photographs. By comparing photos made from aircraft with those obtained from a satellite under similar lighting conditions, scientists learn how to interpret the images correctly. Knowing how various crops appear in a specific area on an aerial infrared photo, for example, enables the crops to be identified in satellite pictures.

Two sensor systems. The business end of the ERTS spacecraft is made up of two sensor systems that operate independently but always eye the same target area. One system consists of three separate vidicon TV cameras which scan a common 100-by-100-nautical-mile square of the earth's surface. Each camera transmits an image in a specific spectral band: green (475 to 575 millimicrons), red (580 to 680 millimicrons), and near infrared (690 to 830 millimicrons).

The vidicon cameras are operated in two modes. In the normal mode, they obtain simultaneous images every 25 seconds until commanded to stop. In the single-picture mode, the cameras will transmit one set of three simultaneous images and wait until another command is received from the ground.

If an ERTS is over a part of the globe that is not in a ground-station line of sight, the images will be stored on wideband video tape for playback, upon command, to a designated station. Pictures provided by the vidicon cameras will have 10 times the detail of images on your TV screen.

The second sensor system is an optical/mechanical multispectral scanner system that produces a strip image by continually scanning a 100-nautical-mile-wide path. This scanner will rapidly sample three wavelengths similar to those detected by the vidicon cameras, plus a fourth spectral band covering more of the infrared region of the spectrum.

Data from this scanner will be fed to ground computers, which eventually will be programed to interpret changes in the images. Computer-processed information will be a must for a worldwide crop survey program because of the torrent of data that will be generated. Since the areas "seen" by the vidicons and multispectral scanner will be the same, data from the two systems may be compared.

Slicing up the spectrum. Why record the planet's surface in a variety of wavelengths? Each object reflects, scatters, absorbs, and emits differing amounts of electromagnetic energy at various wavelengths, giving the object a unique "signature" in a photo. Earth-resource features frequently reveal more information when studied in several wavelengths.

Multispectral scanning enables us to tell a wheat field from an oat field, or a cotton patch from a rice paddy, once ground-truth fields are established to identify crop signatures. Foresters have developed a technique that enables them to differentiate basic tree types by their tones in satellite photos.

Most plant life registers a distinct signature on black-and-white and color infrared film caused by infrared light reflecting from green chlorophyll. Color registered on color infrared film is not the same "natural" color you see with your eyes. (Healthy greenery, for example, appears red.) It is therefore called "false color." The colors actually represent variations in the reflectance of light.

Armchair astronauts. Two separate ground facilities will support and utilize ERTS-A and -B. The Operations Control Center will serve as the cockpit for the "armchair astronauts" who will "fly" the spacecraft through its ever-changing set of assignments. They can monitor the proper functioning of the spacecraft's subsystems via telemetry and inspect the quality of the images.

A Data Processing Facility will receive, process, and distribute the data sent down by ERTS. A lot of pictures will pile up in a hurry. User interest in ERTS is so intense that the processing facilities will be set up to provide more than 300,000 prints per week!

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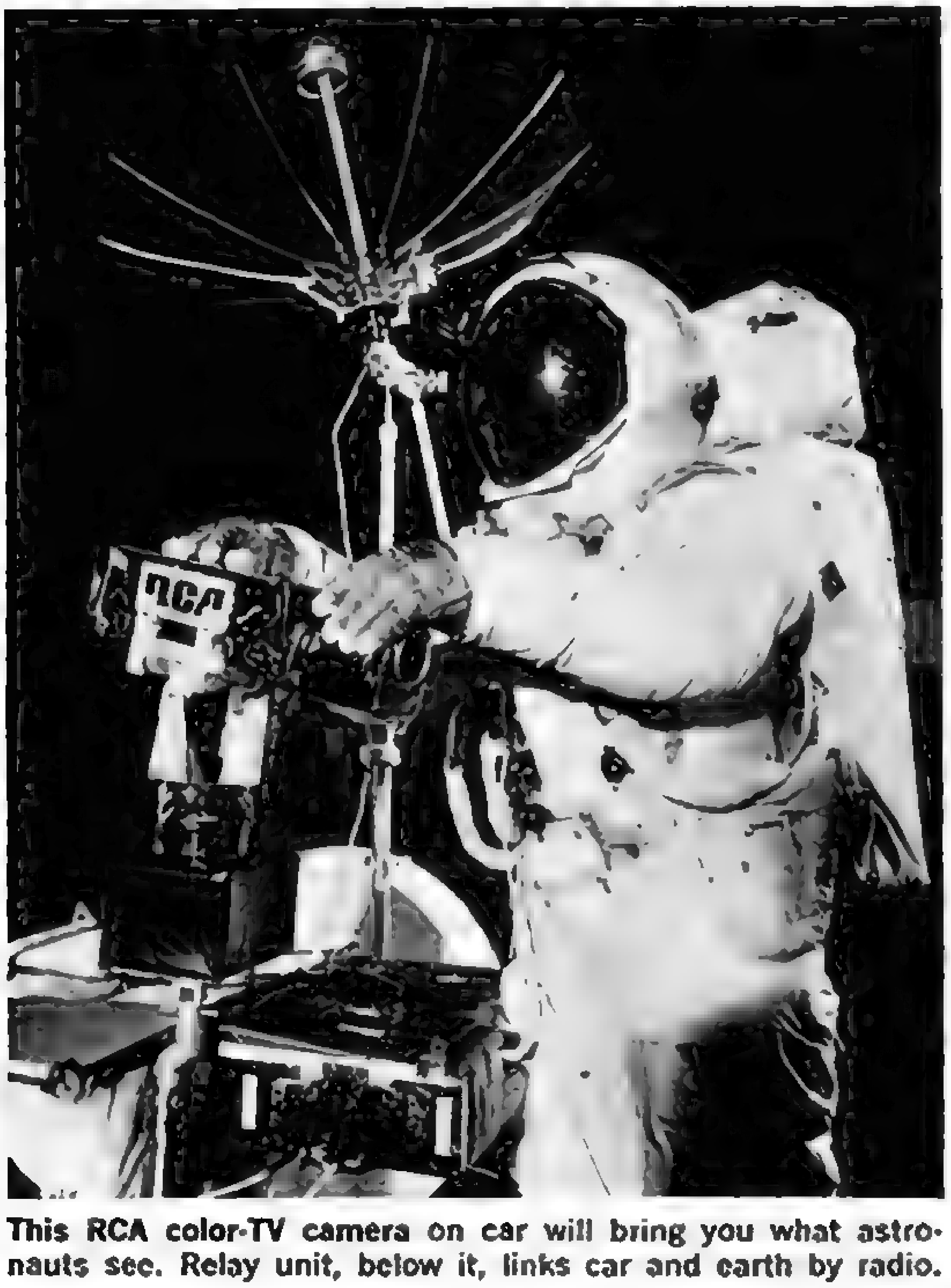
We're Going

What Apollo 15 moon car looks like is shown by this composite version—a "one-g trainer" fitted with woven-wire moon tires instead of rubber tires.

TV will take you riding with Apollo 15's astronauts, this month, in the first manned vehicle on the lunar surface—an eight-mph electric car with tires of woven wire—as their mission begins a new phase of long-staying and far-ranging expeditions to the moon



This RCA color-TV camera on car will bring you what astronauts see. Relay unit, below it, links car and earth by radio.

By
DR. WERNHER von BRAUN
NASA Deputy Associate Administrator
PS Consulting Editor on Space

Dr. von Braun inspects radio-controlled TV camera designed for use in moon car.

When Apollo 15's Lunar Module touches down in the foothills of the moon's Apennine Mountains on July 30, at 6:14 p.m. EDT, it will bring along what the average U.S. tourist expects to find at his destination's airport: a car he can use to get around in.

Apollo 15's battery-powered car, the first manned vehicle on the moon, will enable the astronauts to explore more than twice the area they could cover afoot. A color-TV camera at the front of their two-man open car will take you along with them to see what they see.

With the 12-day mission scheduled this month for the Scott-Worden-Irwin astronaut team, exploring the moon enters a new phase—of long-staying, far-ranging expeditions, compared to those of Apollo 11, 12, and 14. Apollo 15's two-man landing party will settle down on the moon for three days, by far the longest visit yet.

Its modified spacecraft will deliver to the moon's surface twice as much equipment and scientific payload as any previous one. The augmented load will include enough

Motoring on the Moon

oxygen and other consumables to double the amount of time available for adventuring outside. This will permit three lunar-surface excursions, lasting up to seven hours apiece, and totaling 20 hours—more time for exploration than in Apollo 12 and 14 combined.

Our earlier moonmen's crowded schedules of lunar-surface activities have seemed to them like a race against the clock and ebbing oxygen supplies. "There just wasn't enough time," they have lamented. This time, it will be different. There will be ample opportunity to go beyond past tasks of emplacing instruments and collecting rocks—and mount an assault on one of the major mysteries of the moon.

Lunar rivers—or what? Within easy range of the landing site lies Hadley Rille, a gorge resembling a dry river bed on earth. Meandering for 60 miles, typically half a mile wide and 600 feet deep, it offers a fine example of the strange lunar features called rilles. What formed them has provoked lively scientific controversy. Are they actually relics of rivers that once watered the now-arid moon? Were they carved by the flow of dry surface materials, fluidized by gases from the moon's interior? Or are they collapsed lava tubes? The answer could reveal coveted secrets of the moon's past. For on-the-spot clues, Apollo 15 astronauts will observe and photograph the layering of the walls of Hadley Rille—and obtain samples that may tell whether water had a part in shaping it.

Apollo 15's program calls, too, for the first direct probing of the moon's interior—by inserting electronic thermometers in holes drilled 10 feet deep. This heat-flow experiment, originally planned for Apollo 13 [PS Mar. '70], had to be deferred when misadventure canceled that mission's lunar landing.

From lunar orbit, Apollo 15 will be the first mission to loose a moon-circling sub-satellite. It will carry particle detectors and a magnetometer to supplement similar instruments' observations on the moon's surface. Tracking the baby orbiter will refine our data about abnormally dense lunar areas, called mass concentrations or mascons, and may help to reveal what the mysterious mascons really are.

All the way to its finish the Apollo 15 mission will be a novel one. During its return voyage from moon to earth, TV viewers will see the first Apollo space walk in flight, when the command-module pilot makes a 45-minute trip outside the cabin to retrieve films from an instrument package on the Service Module.

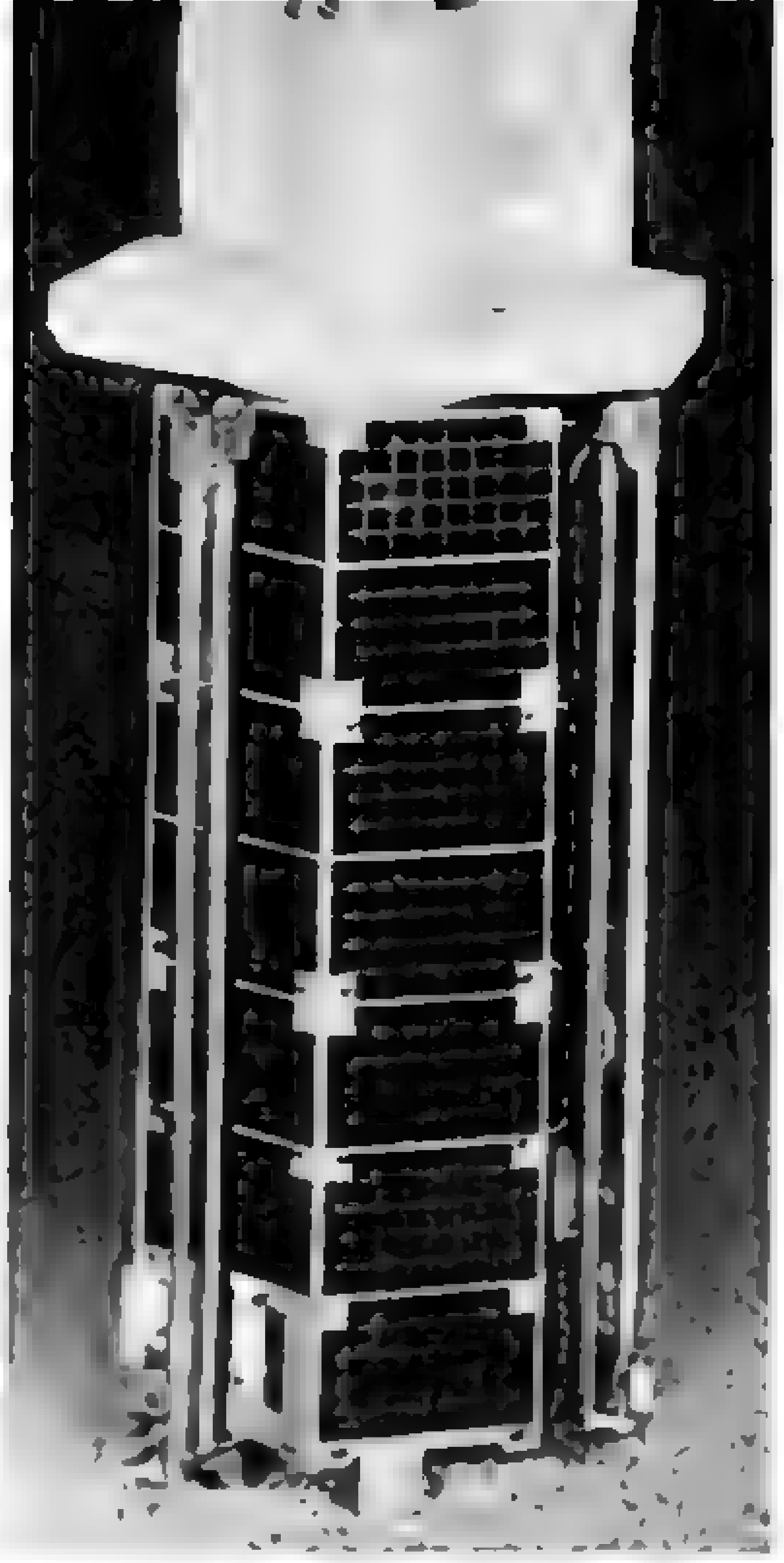
The homecoming moon explorers will be the first to be spared a three-week detention in quarantine, after splashdown. Tests following Apollo 11, 12, and 14 have now convinced NASA's scientific advisers that there is no hazard of bringing back harmful organisms from moon to earth—and quarantine for lunar astronauts and their samples will be eliminated henceforth.

The moon vehicle. If all goes well on this new-style lunar mission, the mechanical star of the show seen by earth viewers will be the moon car.

Its formal name is the Lunar Roving Vehicle, or LRV. The silent-running electric car, built for NASA by Boeing, is about 10 feet long and six feet wide, and has a 7½-foot wheelbase. On a fairly smooth surface it will attain a speed of eight mph.

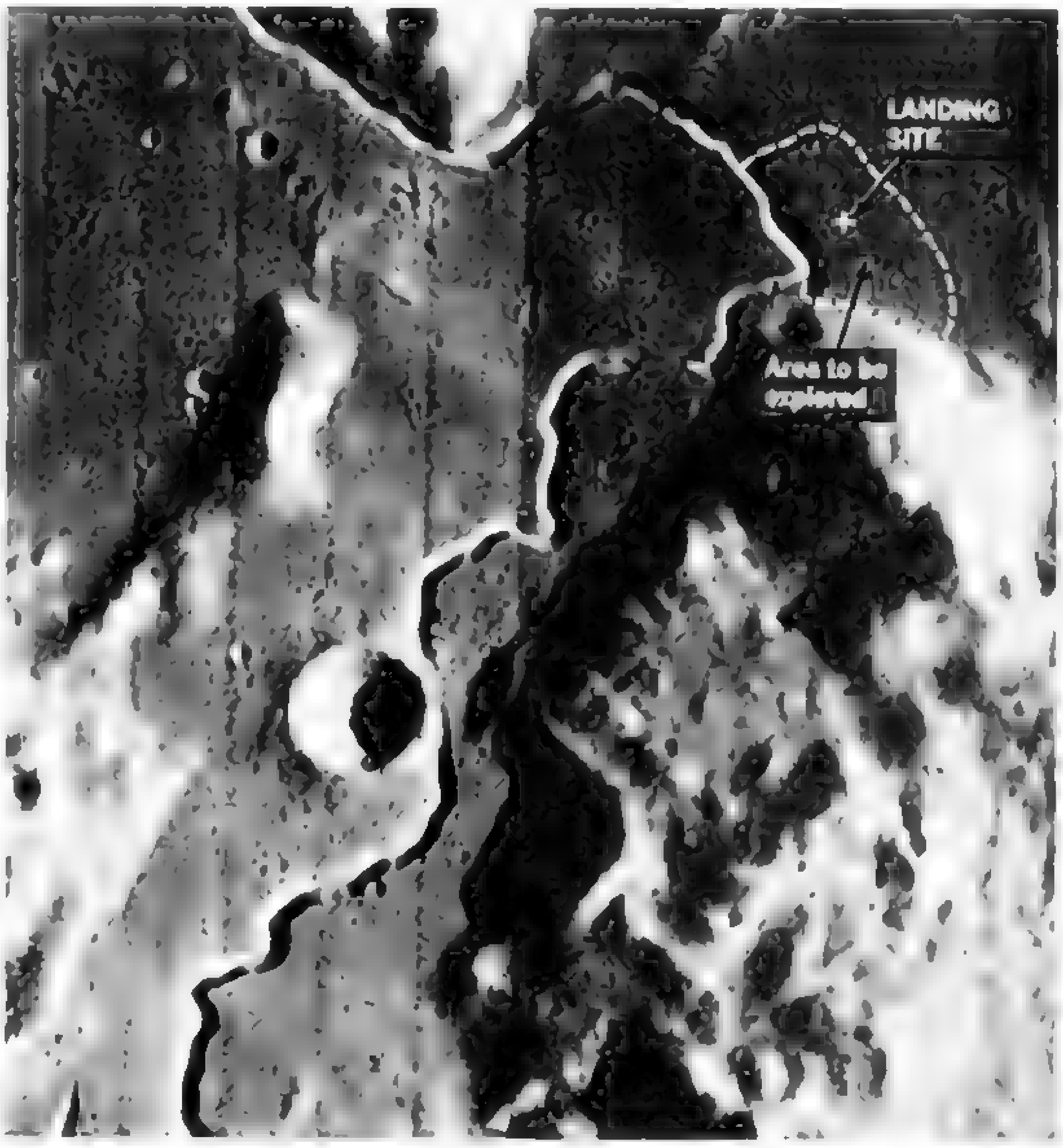
Metal tires are required by the moon's extremes of soil temperature in sunlight or shadow. The LRV rides on

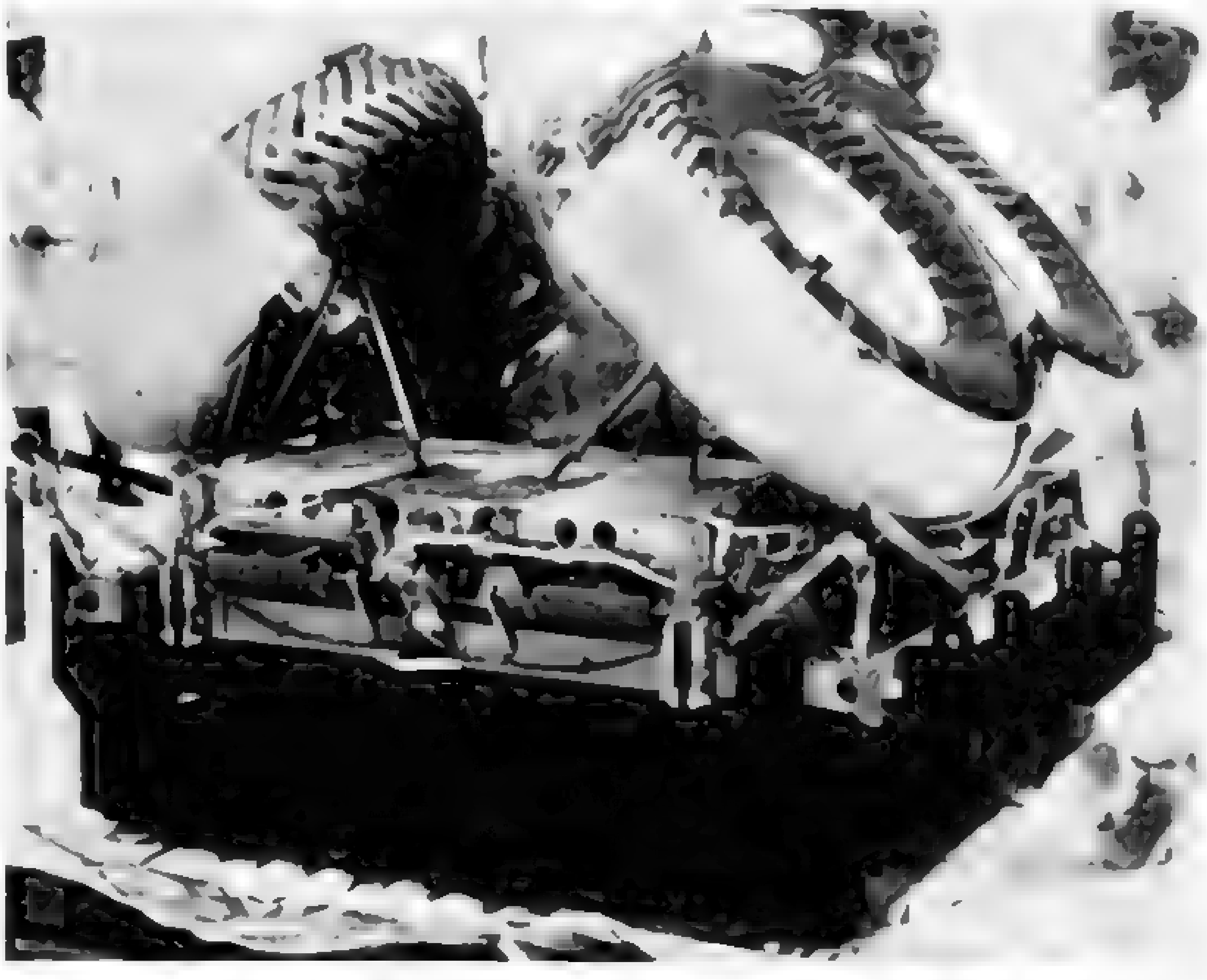
Continued



Baby "sub-satellite" to be launched into lunar orbit from Apollo 15 Service Module, early in mission, will carry instruments to supplement observations of similar ones placed on moon's surface.

Apollo 15 may solve mystery of strange lunar gorges resembling dry river beds—like Hadley Rille, below, winding past crater called Hadley C. Markings show where moonmen will land and explore.





Actual moon car for Apollo 15 is uncrated at launch site. Wheels are folded as they'll be when car rides in Lunar Module.

woven-wire tires, made from zinc-coated piano wire. This mesh has enough "give" to roll smoothly over uneven ground and small lunar rocks. Chevron-shaped treads of titanium metal have been added to give better traction and to keep the wheels from sinking in deep dust.

Fenders of lightweight fiberglass will help to prevent lunar dust kicked up by the wheels from settling on the astronauts and the interior of their car.

Payload far outweighs car. The vehicle weighs about 480 (earth) pounds, including the support and deployment mechanism within the Lunar Module of the Apollo spacecraft. It can carry 1,000 pounds more, of which the astronauts and their life-support equipment take up 800 pounds. The rest is available for scientific instruments, tools, and lunar-rock samples. In contrast with the average family car, which can carry only about half its own weight, the LRV's 1,000-pound payload is more than double its empty weight.

The car's four wheels are individually driven by electric motors, supplied with power from two 36-volt silver-zinc batteries. The batteries' capacity allows the car to travel a total distance of 40 miles, which can be broken up into a number of sorties—like the three which are planned for Apollo 15.

Actually, the riders will stay within three miles of their landing craft, so that they could walk back to it if the LRV broke down, became mired, or tipped over. Even so, the car will enable them to explore 28 square miles, the area of New York's Manhattan Island.

Fully loaded, the vehicle will climb or descend a slope as steep as 20 degrees. From a standing start it can mount a steplike obstacle a foot high, or cross a 28-inch-wide crevasse. Normally using both front and rear wheels for steering, the agile car turns in a radius of only 10 feet.

Instead of a steering wheel, the car has a control stick, somewhat like that of an airplane or the Lunar Module. You push the stick forward to go ahead, move it sideward to turn left or right, and pull it back to apply brakes and

WITH THE APOLLO ASTRONAUTS: Training for

Astronauts Charlie Duke and John Young check their "lunar" charts while reporter Gannon kibitzes. Traverse was over a six-mile course in the Arizona desert.

Activity: rock hunting. Place: Arizona. Trainees: astronauts and one footsore PS reporter

By ROBERT GANNON
PHOTOS BY HAL STEPHENS, USGS

Here's the scene: An incredibly bright sun edges over craggy hills hulking 50, 100 feet overhead. Long, harsh shadows jag across the valley of cinders. The two astronauts—John Young and Charlie Duke—seated in the Rover moon buggy, slowly steer a path among the rocks. They carefully nose the machine over the lip of a crater, then halt. Laboriously, they climb off.

Young photographs a rock, then picks it up with tongs, careful that his huge backpack doesn't throw him off balance.

Balancing fake backpacks, Gannon and Duke climb wobbly ladder to LM mockup.

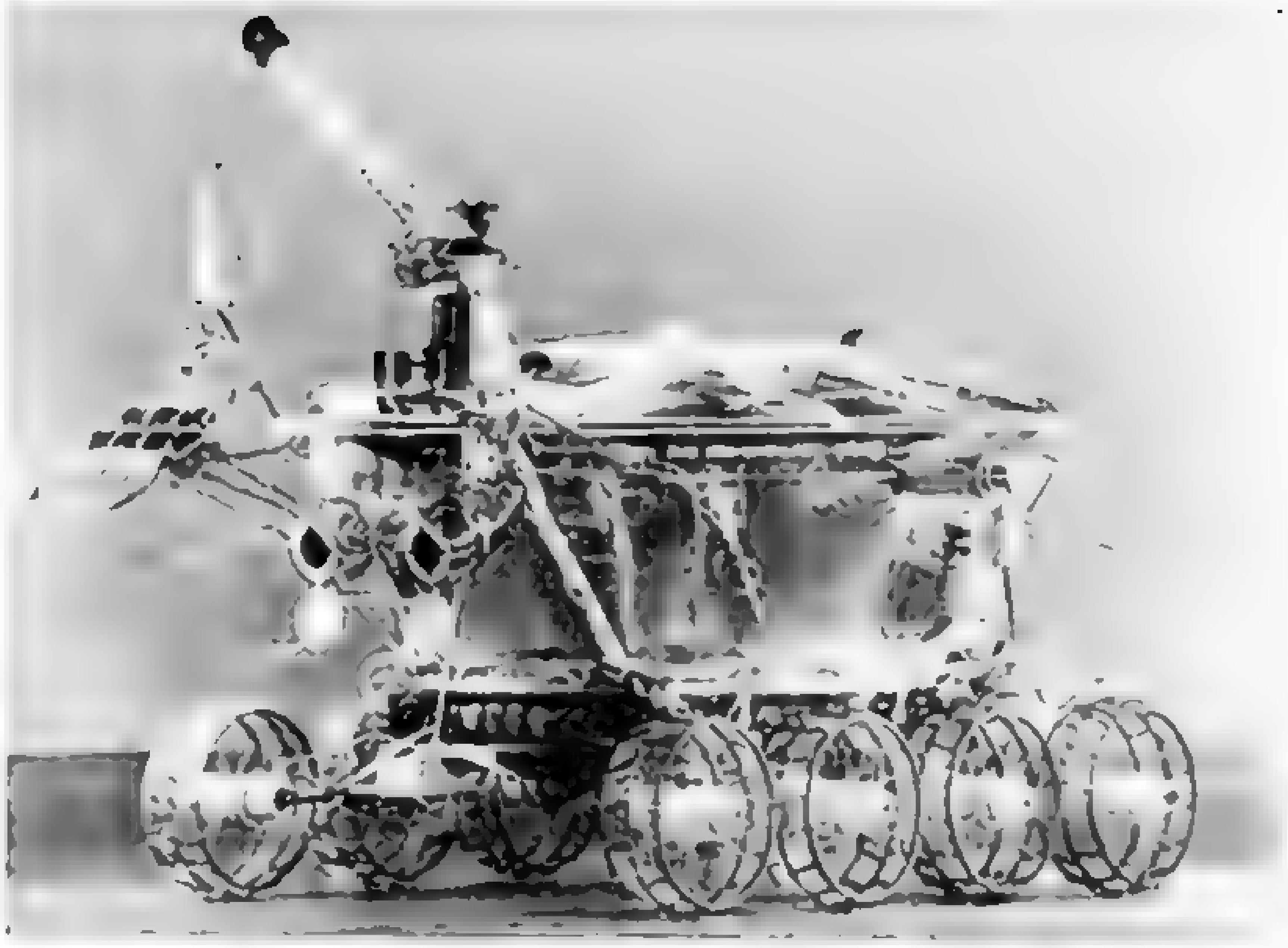
and have a direct radio link to earth

stop. Latched all the way back, it serves as a parking brake. To back up, an electric-switch control system reverses the wheels' motors.

TV by remote control. With no need of help from the moon motorists, the color-TV camera on their car will be operated by radio from earth. Controllers at NASA's Manned Spacecraft Center in Houston will turn it on and off, point it in any direction, pan it around, or zoom in on distant sights—say, to follow the astronauts when they step out to collect samples. The new-type camera, its RCA designers maintain, promises you the best views yet of men exploring the moon.

Even within the safety limit of a three-mile radius from their landing craft, the carborne astronauts frequently will travel beyond sight of it. And this will call for innovations in communication and navigation.

Since communications cannot be relayed via the Lunar Module when the explorers are beyond line-of-sight range [*Continued on page 114*]



Unmanned Russian lunar vehicle, Lunokhod 1, has been exploring moon by remote control from earth, averaging about one mile a month. TV eyes peer through two ports at left end.

the Moon

"All right, Houston, this one is about the size of my fist, and it appears to be basaltic scoria—dark red, full of vesicles, light in specific gravity." He continues the description, then drops the rock into a numbered plastic bag.

The men move on, examining, reporting to Ground Control, photographing, bagging some rocks, disregarding most.

A moon walk? No. You can tell. For one thing, the sky is blue. For another, dust blows around. ("Little trouble with lunar wind here, Houston," says Duke.) And for another, traipsing along behind, notebook in hand, cinders in shoes, exhausted because the Rover has only two seats, is me.

We're out on an all-day jaunt in the squinty brightness of the Arizona desert, six miles northeast of Flagstaff, and we're pretending it's the moon.

The geology—both in the kind of rocks and how they were formed—is rather close to that of the moon's surface. That's important, for we are on a lunar geology exercise.

Prep for Apollo 16. Young and Duke (along with Thomas Mattingly, command-module pilot) make up the Apollo 16 crew, scheduled to hurl moonward next March. The men of Apollo 15 are scheduled to start their journey on July 26, not long after you read this. The two missions will poke around different parts of the moon, but they'll be looking for generally the same things, and their training has been almost identical.

The exercise, conducted by the U.S. Geological Survey, was billed as geologic. But it wasn't, really. The men had learned geology rudiments long ago. Today what Young and Duke were actually doing was, first, rehearsing procedures so they would become habitual. And second, learning to observe, to see.

Already, they were superb at seeing. I looked at the ground and saw simply cinders, about the size of marbles. Slight shadings of color, maybe. The astronauts looked at them and saw not only their size, color, and texture, but noted the slant of the ground, saw that the cinders probably came from *that* cone *there*, that each piece was light, crumbly, with deep, sharp-edged vesicles. They scooped out a hole and noted color changes in the soil layers. And they saw that the whole area differed in color from the surroundings.

Scouting our last volcano. For the exercise, hardly a better location could be found. This part of Arizona is pimpled with craters and cinder cones, the last volcano having blown its top only 900 years ago. The terrain is stark, eerie, unearthly. Moonlike, almost.

The astronauts seemed right at home, even though, except for their simulated backpacks, they weren't exactly dressed for the parts. Young wore a visored golfer's hat, worn pants, scruffy shirt. Duke sported a ripped sweater, jeans, black work boots, and a cowboy hat with rakish feather.

Though each spoke with a sort of plains dialect (why is it that all astro- *Continued*

Duke practices pouring soil into bag. Scoop handle is rake and coring tool.

Duke examines sample of basaltic scoria as Gannon, Hasselblad dangling, watches.

Long-handled tongs save awkward bending. Gnomon (stick) is for color photos.

Gannon tries out earth version of moon machine. Passenger is Putty Mills, the Grover's builder. Control panel at right.

Rover: Learning the principles takes two minutes

Followed by a gaggle of barking dogs and kids on bicycles in a seedy Flagstaff playground, I tried my hand at driving the earthside version of the Rover. My teacher: USGS's vehicle man, Putty Mills.

The principles are easy; you learn them in maybe two minutes. Controls are toggle switches and a T handle. Shove the handle, and the four electric wheel motors gently push you along—either forward or back, depending on which switches you have thrown. Ease the handle back and you stop. Push it to the side and the vehicle turns in that direction.

You bound up and down banks, in and out of holes, over rocks and stumps and rusty cans and broken beer bottles with ease. Both front and rear wheels are steerable to crab sideways—or to move into a tight parking place. To turn tightly, to swivel within the vehicle's length, the rear wheels can be set to turn opposite the front.

But you do this kind of turning in tight spots. When you're heading back to the USGS garage down a suburban street and try this, you overcompensate. Which was what I did. Suddenly the machine was swinging back and forth like a horizontal pendulum—and somehow I couldn't gather my wits simply to apply brakes—not even when the buggy headed off the road into the ditch. But Putty, seated alongside, with a mutter and a pained expression, grabbed the T bar from me and hauled back just in time to avert clipping off a direction sign.

Bet I'd have no trouble on a lunar surface, though.—R.G.

nauts sound like Henry Fonda?), their methods of describing geology were individual. Duke, generally more outgoing and open, kept up a running account of what he was seeing. Young, contemplative and remote, was more selective. But what Young said usually was more scientifically meaningful. This is usually the case, I learned; what one member of an Apollo team lacks, the other adds.

The exercise was essentially simple. As though they had just landed, the men began in a mockup of the LM, a bright-yellow cabana on 12-foot wobbly stilts. I tried to push in with them. But an LM, even a phony one, is a very tight place for two, impossible if everyone is wearing those enormous backpacks. So I watched from outside.

The astronauts were looking out triangular ports, speaking into their face mikes, describing the scene to "Houston"—actually a radio-gear-packed van over the next hill. Then they clambered out, inspected, described, and photographed the local area, and then into the Rover—or "Grover," as everyone there called it (for Geological Rover)—to cover a six-mile traverse.

Rover was a huge hit. This was only the second time the men had used it in an exercise, and they were ecstatic. During earlier outings they—and the moon-walkers—had worn themselves out hiking. Now they rested en route. They also could carry more equipment and specimens, and cover much more territory. The Apollo 15 crew will be the first to ride a Rover on the moon.

The vehicle Duke and Young used *looks* like the moon version, but it differs in a number of ways: Suspension is stronger to counteract the six-times-greater gravity here. Weight is not critical, so the earth model tops 800 pounds, compared with 400 for the flight model. The earth vehicle doesn't fold up, and the wheels have conventional tires. The lunar version has wheels of wire mesh. The earth machine was built by an ex-biker and off-road-vehicle designer named R. A. (Putty) Mills who, working for USGS, put it together for $2,500 in material.

But the one big difference to the astronauts is the feel. In the 1/6 gravity of the moon, as one lunar-vehicle expert pointed out, "if they try to run along and take a bump at six mph, they're going to be airborne a long time—maybe for 20 feet. A lot could happen in that time. I have an idea they'll quickly learn that when they come to a sizable rock, they'll have to halt first, then *crawl* over it."

I get the point. Today, though, out in the desert, they had no trouble. The machine worked perfectly, bumping along at its top six mph. Only one unhappy person—me, plodding along behind. And getting tired of it. Every time I caught up they went riding off to the next interesting-looking hill. That's when I truly learned the value of taking along a buggy.

Actually, I wasn't missing any of the conversation. Strapped to my waist was a radio over which squawked the voices of both astronauts and Ground Control. (At one point I inadvertently fouled up the whole system. Taking a shortcut over a 40-foot hill, I started sliding down the far side, and sat to stop my plummet, wedging cinders under my shirt, in my pants, my shoes—and the transmission button of my radio. The whole Apollo exercise was jammed off the air until I wondered why I wasn't hearing anything.)

Though the men had had photo maps of the area for a couple of weeks, it was only the previous night that they had been given the Flagstaff mission. During an intense two-hour briefing, a geologist and a geophysicist had gone over the details meticulously. But the astronauts were given only as much detail as might be gleaned from orbital pictures of the moon at similar scales.

The astronauts had studied the maps so well that now they recognized formations as they went along. Not so I. At one point I took a shortcut around a serpentine ridge, and when I emerged

[*Continued on page 108*]

With the Apollo Astronauts: Training for the Moon

[Continued from page 54]

on the other side nobody was in sight. I climbed atop—and still nobody—even though I could hear them chattering pleasantly over my receiver.

Lost on the moon? Suddenly, just for the moment before the others emerged from behind a scarp, I felt how it might be to find yourself lost on the moon. You could talk to the others, but how would they direct you to the LM?

Flagstaff geologists, of course, knew the area intimately. But to insure that the astronauts weren't inadvertently given "unknown" information, the selenologists who helped them study the reconnaissance photos were outsiders who had never set foot on the land.

Now, out in the desert, the astronauts were going through a rather set procedure. They were following a route drawn on the maps, stopping at a half-dozen specific points, and others as the mood struck them. They'd find a curious rock or projection and describe it to Ground Control, then photograph it, often moving a couple of feet to the side for another shot. Then they might place the piece in a bag to tote back. Finally they'd photograph the place where it had been.

Usually, as part of each picture series, they'd place a *gnomon* on the ground and photograph it. That's a vertical stick with a color chart affixed, so later, back in the lab, developers can assure exact photo colors.

Occasionally, one of the men would stand on a spot and slowly spin, taking maybe a dozen photos as he turned. Later, these would be put together in a panorama. (The Hasselblad cameras, incidentally, use 70mm film in 180-frame rolls, electrically advanced.)

The men did a lot of estimating of distances. But some experts doubt that practicing *that* on earth does much good. On the moon, no comparison objects exist—no trees or houses or even a reliable horizon. You don't even have haze, so distant objects are just as sharp as those nearby. That's why the Apollo 14 crew came within 50 feet of the rim of Cone Crater and didn't even realize it.

Superobservant men. Young and Duke continued to surprise me with things they saw and I didn't. For example, the edges of exposed rocks, which indicate relative age. If a crater's stones have sharp, well-defined edges, and those of an adjacent one have soft, rounded ones, you know that the rounded rocks have been exposed longer. On the moon, weathering—in the form of meteoritic chipping, solar wind, or cosmic-ray bombardment, and the thermal effects of temperature changes—has eroded away the sharp edges.

When the astronauts saw something weird, they made sure they identified it as such. "An amateur collector is attracted mainly by specimens that stand out," Hal Stephens, USGS geologist, explained later in the lab. "Back home with only these oddballs, the impressions would be that they are the common ones, and the whole evaluation would be thrown off. The offbeat rocks *are* important, of course, but the professional is just as interested in *representative* samples."

"Actually, these guys have gotten really good," added George Ulrich, geological director of the exercise. "They're turning into excellent observers. The surface here is pretty mundane, yet they see subtle differences in rocks and soils—texture, color, minerals, reflectiveness."

Stephens agreed, but added: "The question we always ask now, though, is how well will they do on the moon? Here they give excellent, in-depth descriptions. But there, under stress and excitement, we found in the past that the men tend to use nondescript terms. They say, 'that stuff there,' or 'that funny-looking rock there,' and it drives us insane. That's why we try to get them to photograph the hell out of everything. If they take enough good pictures, maybe we'll start solving some of the mysteries."

Mysteries. The moon is still full of them. For instance:

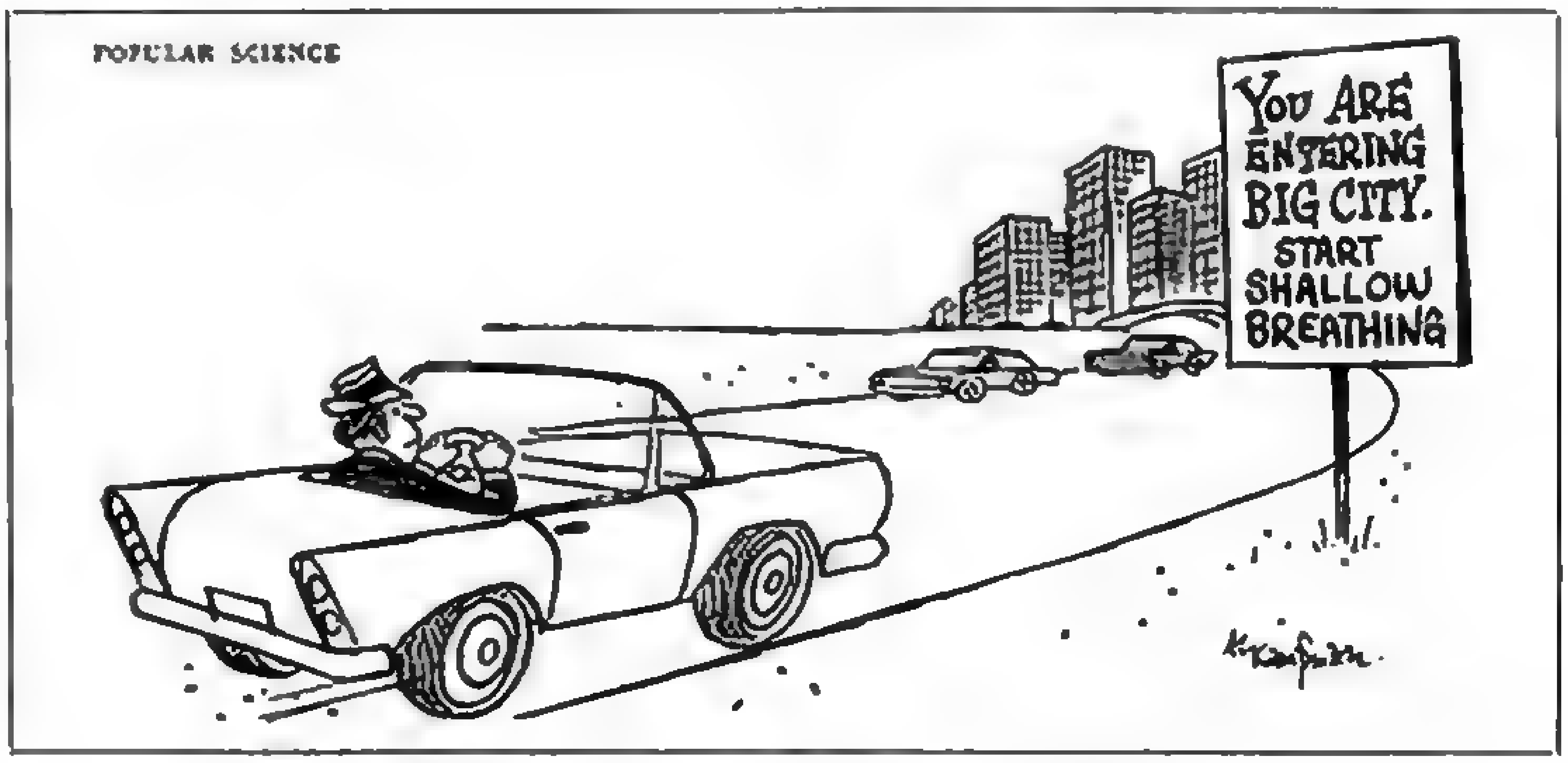
- In some fields of old, eroded, rounded-edge rocks, an occasional chunk with sharp edges is found—presumably a "new" one. Where'd it come from?
- Most of the moon's craters were formed by meteoritic impact, or by volcanic activity, but some may have been formed by gas escaping from inside, resulting in a fluidized condition. Some scientists say impossible. Who's right?
- Hadley Rille, site of the Apollo 15 landing, is a 60-mile-long canyon several hundred feet deep, a mile across in places. What caused it? Collapsed lava tunnels? A kind of volcanic ash erosion? Was water involved? Nobody knows.
- Seismometers left behind by the astronauts record a considerable amount of jarring. What causes that? Landslides? Meteoritic impacts? The moon groaning under the tug of earth gravity? Moonquakes?
- When such a shock occurs, the reverberations last far longer than theory says they should. Instead of rumbling a few minutes, as on earth, they may echo for an hour or more. One expert says the theoretical best lunar model that would accommodate all the figures "would make for a rather bizarre moon . . . a hollow titanium ball."
- When Young was orbiting the moon in the Apollo 10 capsule, he saw things that no one can explain. Strange colors that don't belong. Split, bulbous domes that defy rational explanation. And "The Thing," a ridge that winds sinuously across the surface.
- Some rocks have fillets—dust and sandy material lying between the rocks and the surface, as though blown there. No wind, of course, so the soil probably was either splashed there by meteorites, or fell from the rocks themselves. Trouble is, some rocks with fillets have been found sitting alongside similar ones without fillets. Nobody knows why.

One mystery was presented even during the Arizona trek. On the lip of a small crater, looking as though it had been ejected just the week before, was a rock about the size of a muskmelon. Reported Young: "Houston, you ain't a-gonna believe this rock, but I'm documenting it with photograph 128 for proof. It's fully banded, a general brownish color with pockmarked weathering—and get this: It's petrified wood!"

"Based on your geologic knowledge," coolly responded Control, "what would you say was the specimen's origin?"

"Based on my massive training, my conclusion is that it's here through an Act of God."

Wrong. It was the act of one of the geologists who slipped it in.



1972

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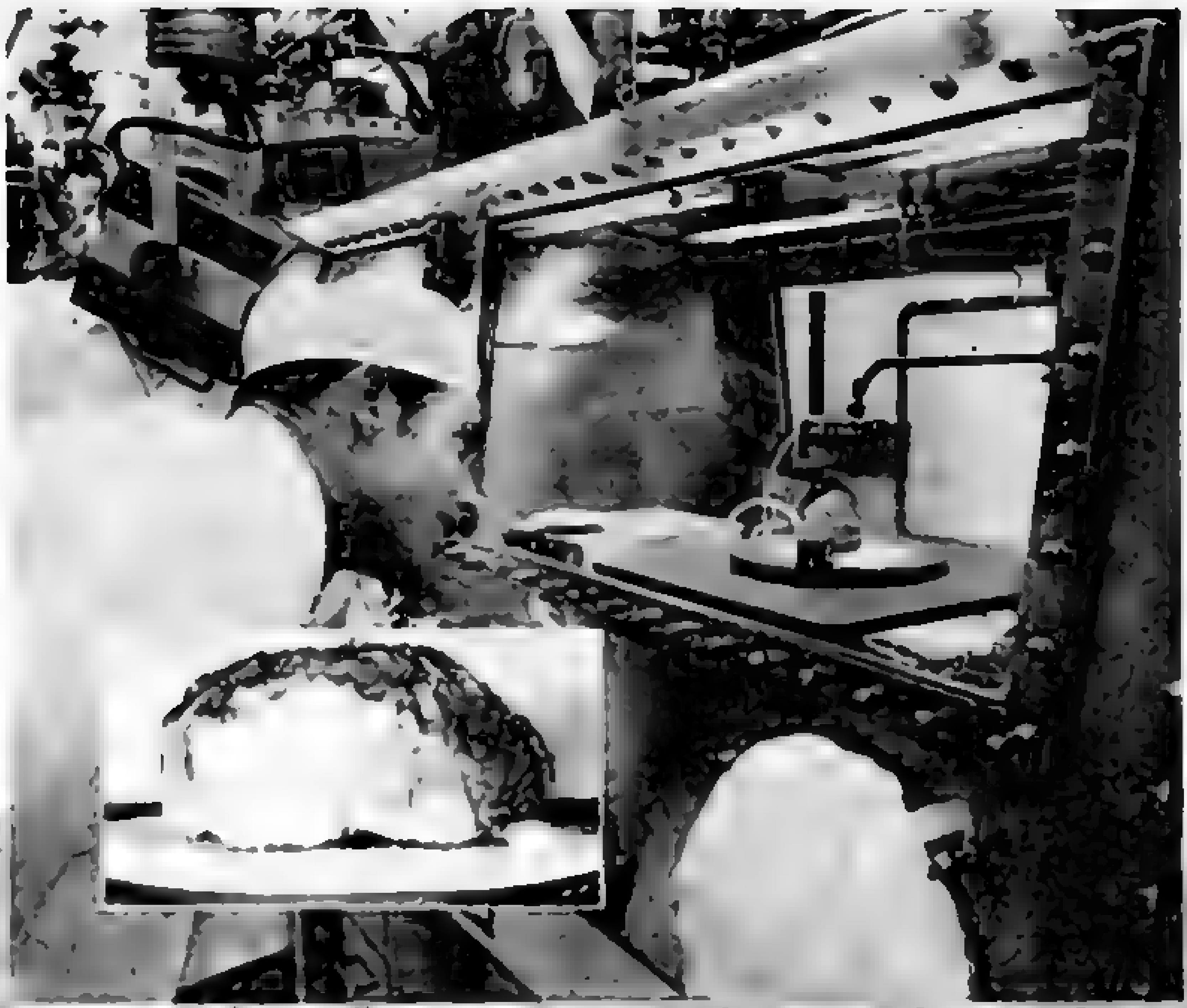


Astronaut Scott peers at a "genesis rock," which may be 4.1 billion years old. Inset shows its whitish, crystalline interior.

A spectacularly successful mission answers some questions—and raises more

Apollo 15's list of finds and new insights is not yet complete, but already its scientific booty far exceeds returns from the trailblazing earlier missions.

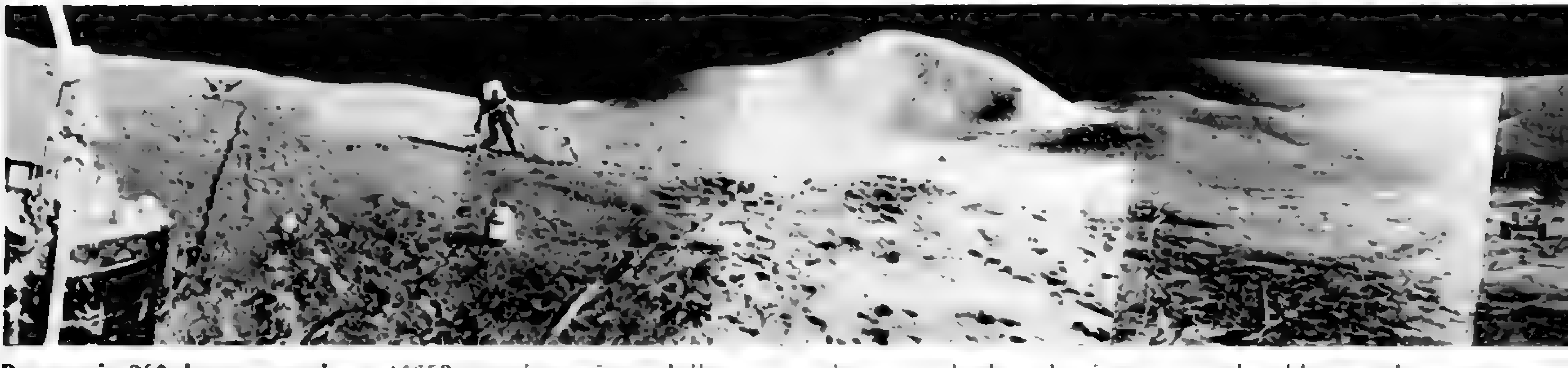
The 15 crew returned with 168 pounds of lunar surface material that included 59 rock samples weighing more than 25 grams each. This is a little more than 75 percent of the combined weight of all the material returned by Apollos 11, 12, and 14.

The painstaking care that Cmdr. David R. Scott and Lunar Module Pilot James B. Irwin took in collecting and documenting their samples pinpoints 57 of the 59 rocks at precise locations on the detail map of their land excursion; 45 rocks can even be properly oriented on the basis of the photographs.

The 21 pounds of "Great Scott" basalt with 23.1 percent iron oxide has the highest iron content of any lunar rock found thus far. The whitish "genesis rock," composed almost entirely of plagioclase (calcium-sodium-aluminum-silicate), is certainly one of the most exciting finds ever made on the moon.

More than seven pounds of the samples were taken from a depth of approximately 13 inches with the five drive tubes; about three pounds were taken with the deep-drill core, which went to a depth of about eight feet.

Experiment-packed Apollo 15 above the Hadley-Apennine area (looking north). Landing site is just to right of "chicken beak" formed by Hadley Rille (bottom).



Panoramic 360-degree mosaic at ALSEP site shows Scott drilling holes for heat-flow experiment. Central-station seismic-experiment package is at both ends of mosaic, with cables to other sensors. Moon rover is parked in front of Falcon lunar module. Pan extends

By DR. WERNHER von BRAUN
NASA Deputy Associate Administrator
PS Consulting Editor on Space

Our Ideas About the Moon

Interior temperatures. The heat-flow experiment has yielded its first data cycle for one complete month, or one lunar orbit around the earth. Surface temperature varied between +86 degrees C at local high noon (a bit after full moon) and −185 degrees toward the end of local lunar night.

However, a mere three feet below the surface, the diurnal variation was found to be in the order of only a few thousandths of a degree! The string of temperature gauges inserted into a drill hole clearly indicated a steady increase of the temperature level with depth, at a rate of about one degree per foot.

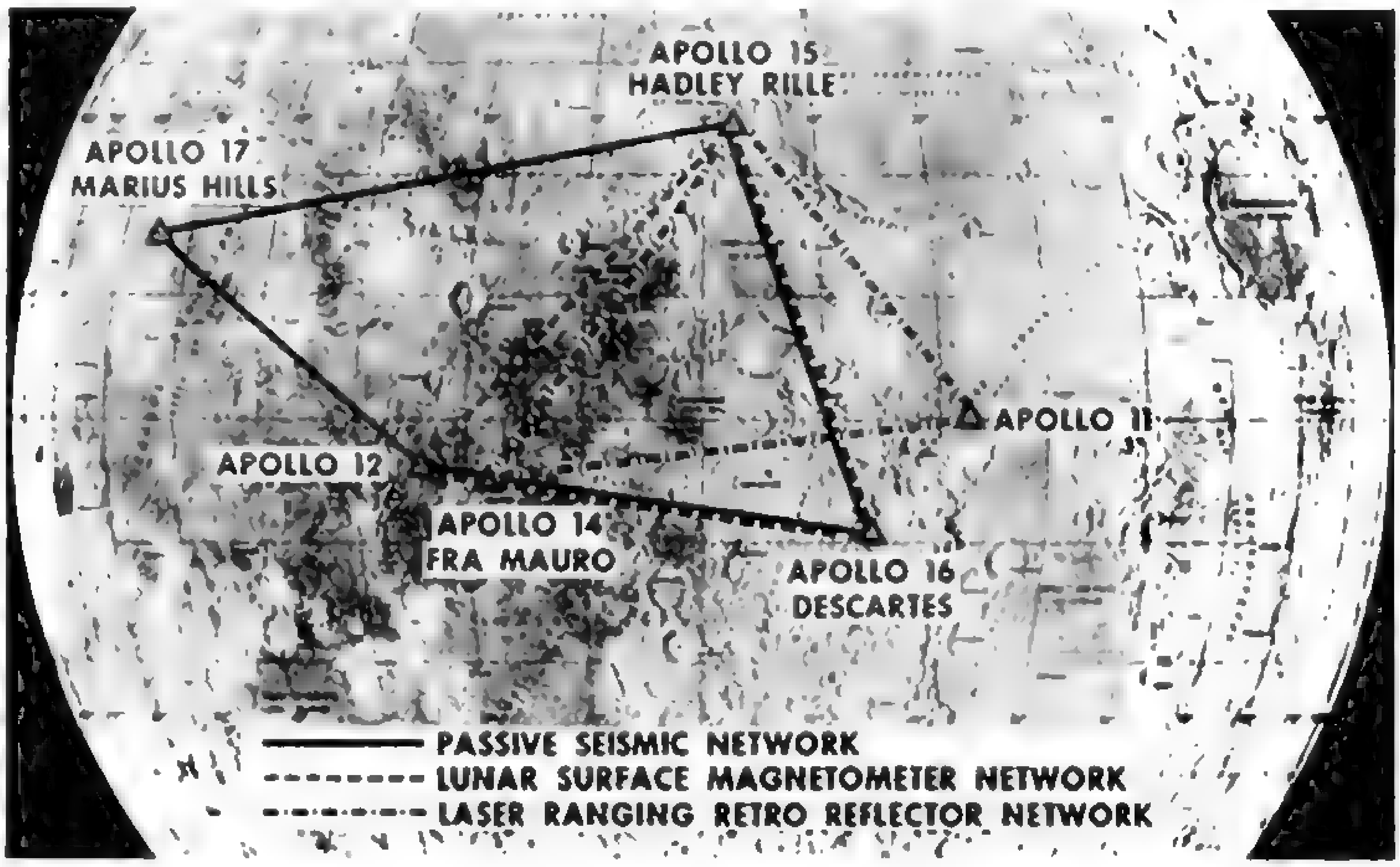
Thus Apollo 15 firmly established that on the moon the same situation exists that we know so well here on Earth: As you descend deeper and deeper into a mine shaft, the temperature increases, because the Earth's interior is hot. On the moon the reason can only be the same, and thus Apollo 15 seems to have settled an old scientific argument between the "cold mooners" and the "hot mooners" in favor of the latter.

Radioactive heating. Preliminary results of the Apollo 15 heat-flow experiment indicate the heat flow from the moon's interior outward is about one-fifth that of Earth. Interestingly enough, this is the figure you would expect if you consider the relative volumes and surface areas of the two bodies, and assume the main source of the outward heat flow is heat produced by a similar mix of radioactive materials such as uranium, thorium, and potassium.

Apollo 15 placed the third ALSEP (*A*pollo *L*unar *S*urface *E*xperiments *P*ackage) on the moon. By September 24, 1971, it had been working well for 55 days. Along with the Apollo 12 ALSEP in the Ocean of Storms (in operation for 674 days) and the Apollo 14 ALSEP at Fra Mauro (in operation for 231 days), the Apollo 15 station has given us a very effective science network on the moon.

Science stations on the moon

Network of stations beaming data to Earth is growing. Moonquakes can be pinpointed using sensors at Apollo 12, 14, and 15 sites; other experiments map distances, record magnetic fields.



All ALSEP stations are equipped with passive seismometers, and the network now permits us not only to determine the location of meteoroid impacts on the lunar surface, but in the case of moonquakes, depth as well.

During the first lunar perigee after deployment of the Apollo 15 ALSEP, a large moonquake occurred and was promptly nailed down by triangulation at approximately 450 miles beneath the surface and 370 miles west of the crater Tycho.

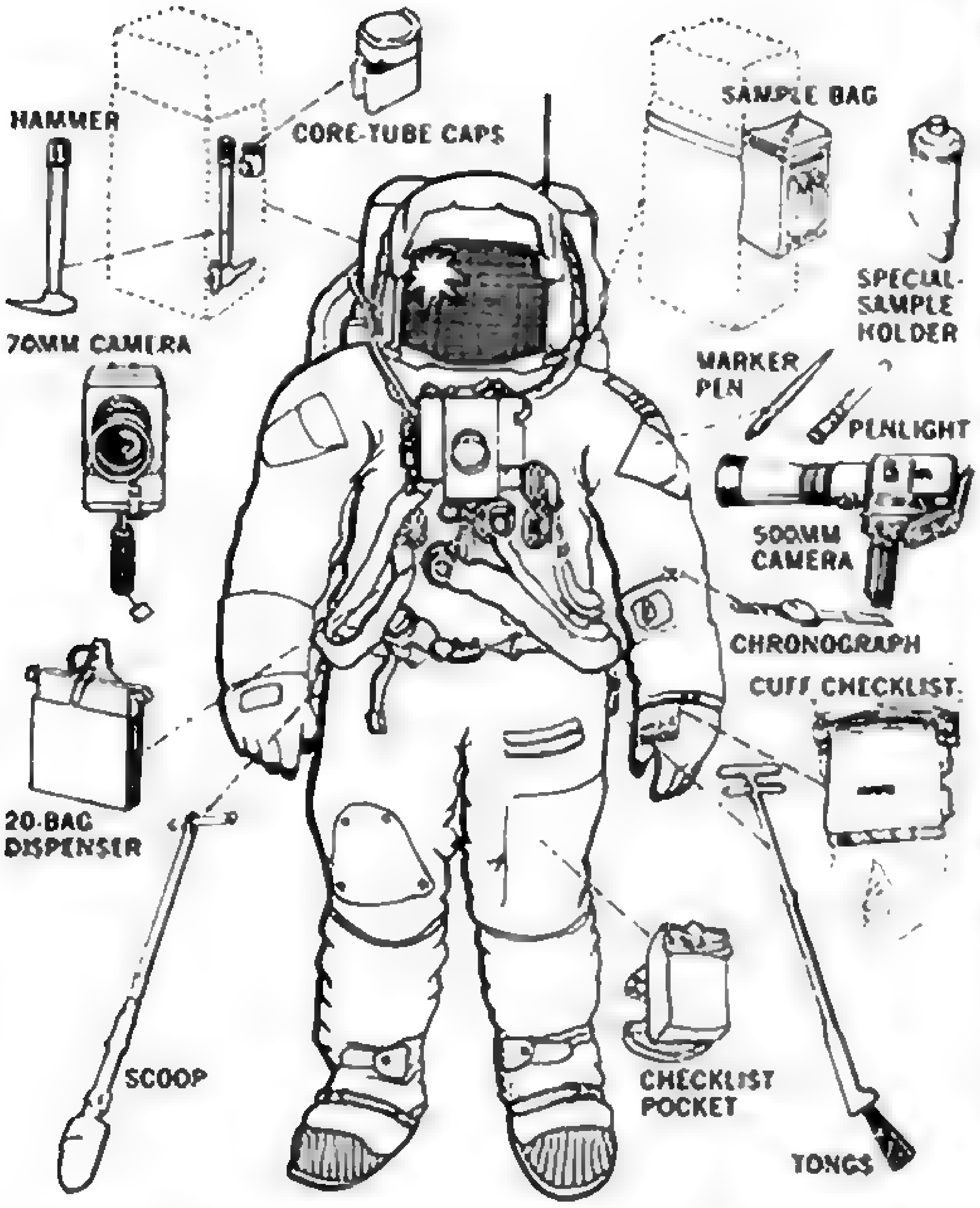
Seismic impulse puzzle. The propagation velocity of the seismic waves through the depths of the moon's body has given scientists new insights into the nature and stratification of the lunar interior. The velocity seems to gradually increase down to a depth of about 15 miles—then there is a sharp increase.

This abrupt increase can only be accounted for by a change to a denser material, possibly the base of a lunar crust formed at an earlier geological age. At a depth of 40 miles, the velocity is estimated to be about six miles per second. Velocities that great do not occur in the earth until depths of some 300 miles!

This discrepancy is all the more remarkable, for under the six-times-

Continued

from Mt. Hadley (left) to Mt. Hadley Delta (right). St. George Crater is on right edge of Hadley Delta slope and Hill 305 is far right on horizon. Site is marked with footprints of astronauts who set up the still-operating experiments.



Well-equipped to explore the desolate surface of the moon, Scott is shown at work above (his gear, left). Tongs in his hand simplify picking up samples; bending is difficult in pressurized, bulky spacesuit.

stronger gravity on Earth, the upper layers exert a much greater weight and compacting pressure on the underlying strata. No rocks examined thus far would, under the actual pressures expected at a lunar depth of only 40 miles, transmit seismic impulses at speeds as high as six miles a second. This is just one of many new questions Apollo 15 brought home.

Lunar photography. While Scott and Irwin were exploring the canyon-like Hadley Rille and the foothills of the lunar Apennines on the surface, Command Module Pilot Alfred M. Worden was just as busy in his 74 orbits around the moon. With his mapping camera he produced 3,400 high-resolution photographs of excellent quality.

Of the lunar surface overflown in daylight, magnificent stereoscopic photography was obtained that provides elevation data for mapmakers and useful information for geologists.

The gamma-ray spectrometer in Worden's orbiting CSM clearly identified lunar areas of different radioactivity levels. Mare Imbrium and Oceanus Procellarum showed highest readings, Mare Crisium and Mare Serenitatis somewhat lower, and the highlands, particularly on the moon's far side, the lowest of all.

Survey in orbit. Measurements by X-ray spectrometer showed the lunar eastern highlands two to three times higher in aluminum content than the mare basins, and the lunar far-side highlands even richer in aluminum. Lunar minerals emit telltale secondary radiations from bombardment by solar radiation [PS, Feb. '70].

A rather unexpected discovery was made by Worden's mass spectrometer. It indicated that the amount of gas at his orbital altitude around the moon was about 10 times higher than that recorded on the way back to Earth. Gases detected included water vapor, carbon dioxide, and a variety of hydrocarbons. Worden's laser altimeter showed that, relative to an idealized spherical moon, the average lunar far side is about 6,000 feet high, whereas the average front side is about 6,000 feet low. The moon thus resembles a pear with the stem pointing away from the Earth.

Analysis of all the data, samples, and pictures is underway. But even after everything is sorted out, it will be next to impossible to identify what lunar scientists have learned from Apollo 15 only. Every one of the previous Apollo flights, as well as their unmanned predecessors (Rangers, Surveyors, and Lunar Orbiters) have raised new questions while adding bits and pieces to the jigsaw puzzle of the moon and its history.

We are left with these basic questions: How far has science progressed in assembling the total puzzle? What is the latest scientific opinion on the moon's origin and history? While there is still much disagreement on details, the following story of the sun, the Earth, and the moon seems to find ever-growing acceptance:

Creation from collapse. Our solar system was formed from a primordial cloud of dust and solid debris. Gravitational collapse of the cloud formed the sun, but all cloud particles with tangential speeds high enough to prevent their falling into the sun kept orbiting around it. Mutual gravitational attraction between these orbiting parts gradually aligned them in the plane of ecliptic.

Random accumulation of some heavier parts formed gravitational centers which, after many revolutions around the sun, gradually sucked up the remaining particles like a vacuum cleaner. One product of this accretion was our own planet. All the planets were formed in the same manner. The sole exception is the asteroid belt, where parts in similar orbits thus far have failed to condense into a planet.

Just as the material that formed the planets had too high a tangential speed to fall into the sun, some material attracted by the accreting Earth stayed in orbit around Earth instead. It formed a subgravitational center whose gravitational collapse then produced the moon.

Impact melts parts. Radioactive dating and other methods led scientists to believe the near-simultaneous birth of both the Earth and its moon took place about 4.6 billion years ago. There is reason to believe the newly born moon was much closer to Earth than it is today. The heat produced by impact melted the myriads of impinging parts. The lighter material floated to the surface and soon cooled off through radiation.

The moon's first solid surface, formed about 4.5 billion years ago, was a rock "scum." But impacts from the continuing accretion process continued to pound the hardening crust—shattering it, cratering it, and altering its minerals.

Half a billion years later, the crust had substantially thickened, and only an occasional heavy accretion impact (or shall we now call it a meteoroid?) cracked it here and there. These blows let lava from the hot interior ooze up, filling basins and older craters with basalt-like rock, sometimes several miles thick.

Missing clues to history. Thus the moon today provides us with a museum full of frozen evidence of its earliest history. And since the moon's early history is virtually identical with Earth's, the lunar rocks now bring us unprecedented insights into Earth's early years, of which we knew virtually nothing. For on Earth, continental upheavals, ocean water, river sedimentation, rain, wind, and vegetation have virtually eradicated all fingerprints and clues of the first two-thirds of Earth history.

Mankind depends on the Earth's mineral resources for survival. Who can tell today what eminently practical consequences may one day spring from man's better understanding of Earth's geological history?

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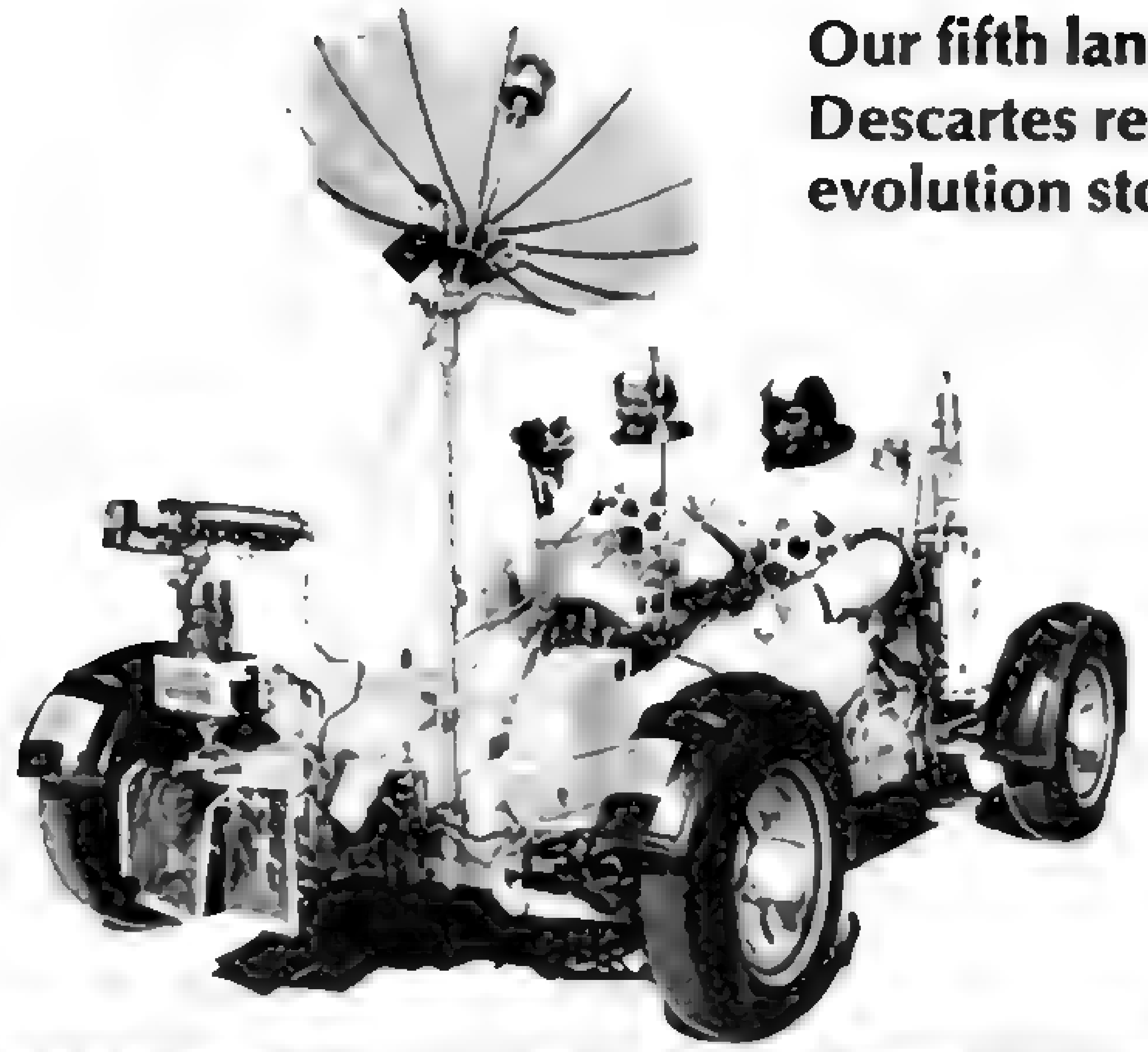
Our fifth landing mission is slated for the mountainous Descartes region. Geological samples will round out the lunar evolution story as experiments probe for other moon secrets



APOLLO 16
Exploring the Lunar Highlands

By
DR. WERNHER von BRAUN
NASA Deputy Associate Administrator
PS Consulting Editor on Space

Ignition! A jet of yellow-orange flame, triggered by the on-board computer, erupts from the Lunar Module's descent engine at precisely 2:54 p.m. EST on April 20. Twelve minutes later, if Apollo 16's timeline continues as planned, the LM will settle in the rugged Descartes region. Man, for the fifth time in four years, will set out to explore the desolate lunar surface.

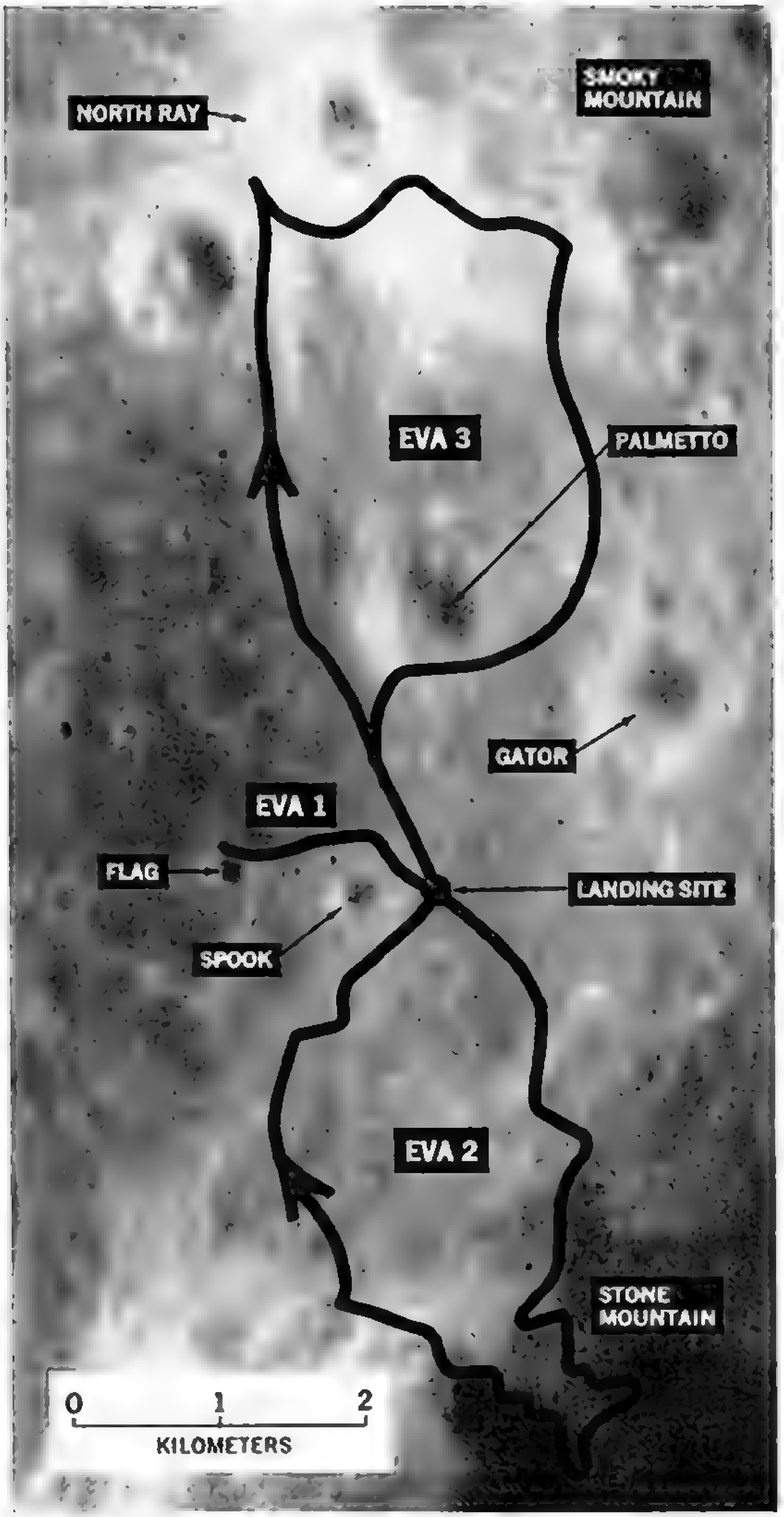
As the descent engine whines beneath their feet, Commander John Young and LM Pilot Charles Duke will arc downward toward the central lunar highlands. The Descartes landing site is surrounded by some of the most starkly beautiful terrain yet visited by astronauts—topographically one of the highest regions on the Earth-side hemisphere.

This site has been selected to complement the 1969 Apollo 11 and 12 missions to mare areas, Apollo 14's Fra Mauro upland site, and 15's exploration last July of Hadley-Apennine, a northern plain flanked by high mountains and a deep gorge. Apollo 16's site, as we'll see, provides distinct geological sampling objectives to help fill the gaps in lunar models developed thus far. A battery of scientific experiments is also planned.

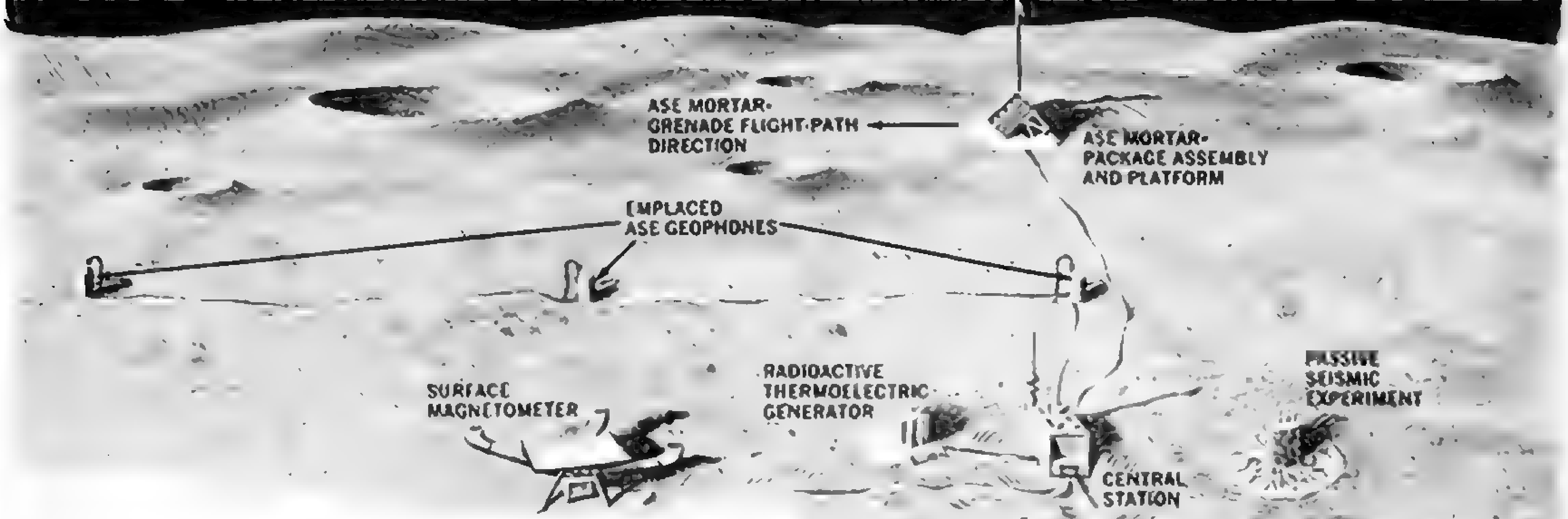
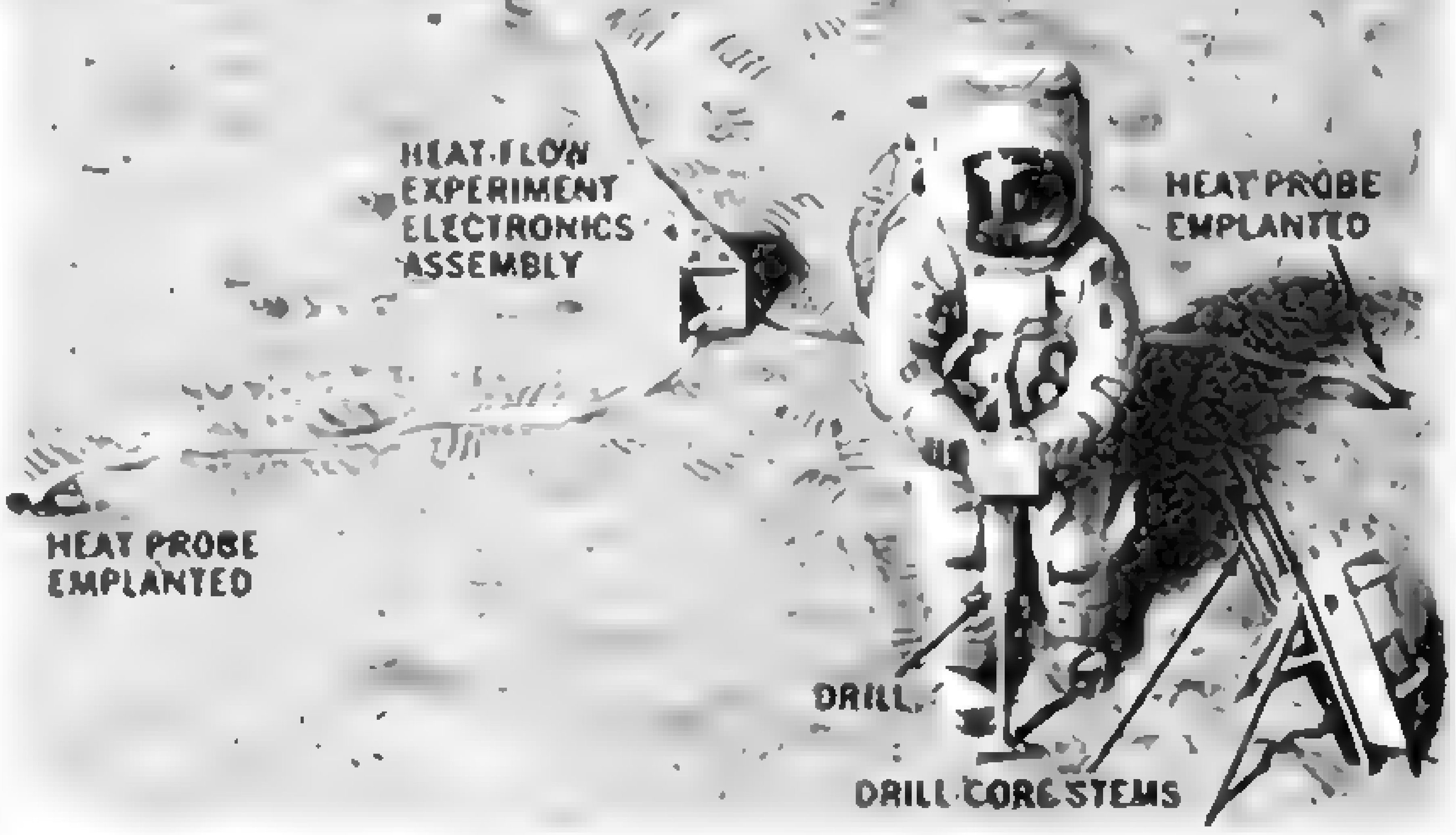
Blastoff from Kennedy. The mission is scheduled to get underway at 12:54 p.m. EST on April 16. Twelve minutes after the Saturn 5's five first-stage engines come to life, the third stage will be shut down and the spacecraft will enter a 90-nautical-mile circular parking orbit around the Earth. At 3:44 p.m., the third stage will have completed its second burn and Apollo 16's three-day unpowered flight to the moon will have begun. Twelve days later, on April 28 at 5:30 p.m. EDT, the Apollo 16 crew will splash down in mid-Pacific.

Skipper of Apollo 16, John W. Young, is a veteran of Gemini flights 3 and 10. John also served as command-module pilot on Tom Stafford's Apollo 10 "dress rehearsal" flight. Young's companion on the lunar surface, Charles M. Duke Jr., played a major part in many Apollo flights as capsule communicator at the Houston Mission Control Center. Thomas K. Mattingly II, who missed the ill-fated Apollo 13 flight because of exposure to German measles, will be command-module pilot.

Once at the Descartes site, the astronauts will explore and obtain samples from two lunar formations. The first involves the highlands basin fill. This is a volcanic-appearing material, flooding many of the old highland



Astronauts Duke and Young (top) practice with Lunar Rover similar to vehicle that will carry them over looped routes to sampling sites. They'll be on the lunar surface for three days and nights.

Central station receives data from site experiments and transmits the information to Earth. The mortar can be fired from Earth. Crewman here is drilling for a deep-core moon sample.

craters. With the younger material sampled in the mare landing sites of Apollo 11 and 12, older Imbrium-basin ejecta sampled by Apollo 14, and the very old rocks returned from Apollo 15, scientists should be able to further round out the story of lunar evolution.

A second sampling objective is the hilly, grooved and furrowed terrain also thought to be volcanic. Called uplands volcanics, these areas may be of similar age but different composition than the basin fill. Just as the mare basalts help identify the interior composition in mare regions, the upland volcanics will yield data on the interior composition of the thick highlands crust. Fresh impact craters up to one-half mile in diameter near the site should permit selective sampling to 600-foot depths.

Roving the moon's surface. The first extravehicular activity (EVA) will involve inspection of the LM, "grab bag" sample collections close to home, and deployment of the Apollo Lunar Surface Experiments Package (ALSEP). Also, the Lunar Roving Vehicle (LRV) will be removed from its LM cradle, unfolded, checked out, and used for a short ride. EVAs 2 and 3 will be round-robin land traverses to sites up to five miles from the LM.

Apollo 16's ALSEP will be similar to the three still-operating ALSEPs left by Apollos 12, 14, and 15. Most ALSEP instruments furnish local data, which are carefully compared to better understand phenomena involving the entire moon. However, the passive seismic experiments form a regular seismic network that can nail down the location of a distant meteoroid impact or a moonquake through triangulation.

Electrical power for the ALSEPs is provided by a Radioactive Thermoelectric Generator (RTG), which converts heat generated by a radioactive fuel capsule into electricity with the help of a thermocouple bank. One of the first tasks on the lunar surface is to transfer the radioactive fuel capsule from a crashproof cask on the LM descent stage to the RTG's converter casing.

Then the two subpackages making up the ALSEP unit (see photo) are separated so an astronaut can carry them like a barbell with the ALSEP antenna mast. When the various experiments are deployed, all elements are electrically connected with a central station that radios data back to Earth and receives instructions from Earth after the astronauts have departed.

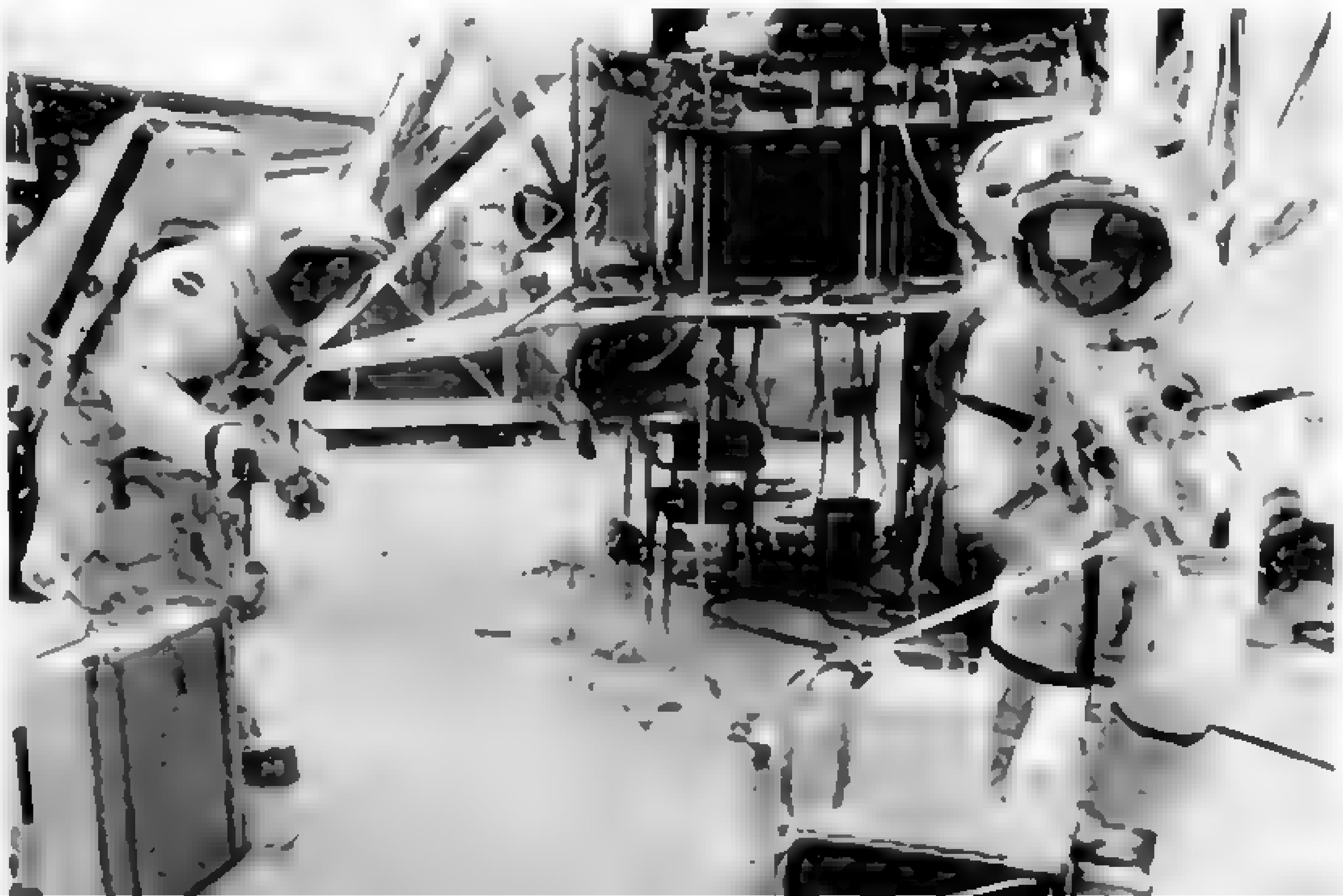
Launching rocket grenades from Earth. Close to the central station will be the Passive Seismic Experiment (PSE). Its purpose is to measure seismic signals originating anywhere on the moon's surface (meteoroid impacts) or in its interior (moonquakes). The time required for seismic waves to reach each ALSEP station tells geologists a great deal about the interior makeup of the moon. The PSE looks somewhat like a large tin can and houses three mass-spring seismometers for the up-down, north-south, and east-west components of the tremors; in addition, there is a fourth seismometer for short-period up-down movements of higher frequencies.

The Active Seismic Experiment (ASE) will furnish data on the physical properties of lunar surface and subsurface materials. A string of three geophones about 150 feet apart will receive natural and artificially produced seismic waves. But since the central station can activate the power- and channel-consuming ASE only an average of about 30 minutes per week, we cannot rely on natural seismic-wave sources. The waves are therefore generated by a "thumper," a sort of pneumatic road hammer driven by shotgun charges fired by an astronaut at 15-foot intervals as he walks along the geophone line.

Apollo 16 introduces a novelty to the Active Seismic Experiment: A little rocket launcher will fire grenades up to 5,000 feet by Earth command after the astronauts have departed. The high-explosive charges will detonate on impact, and each grenade is equipped with a timing

[*Continued on page 144*]

Two subpacks, deployed from LM mockup in background, contain experimental apparatus that Duke and Young will set up at site.



Apollo 16—Exploring the Lunar Highlands

[Continued from page 81]

transmitter that provides precise time-of-flight and impact data to the ALSEP central station, which relays the data to Earth.

Another important ALSEP experiment is the Lunar Surface Magnetometer. It will determine the presence, strength, and orientation of a magnetic field at the landing site, and monitor possible variations. The sensor consists of three so-called flux-gate magnetometers, one at the end of three orthogonal booms aligned at right angles to one another. Each boom-mounted sensor can be rotated by small, automatically programed electric motors to perform a survey of any magnetic field encountered.

Lunar heat loss. The ALSEP Heat Flow Experiment, like its Apollo 15 predecessor, will determine the rate of heat loss from the lunar interior. Using the Apollo Lunar Surface Drill an astronaut will first drill two holes down 10 feet [see PS, Dec. '71].

Two probes, each about four feet in length, are inserted into each of the holes. The probes are equipped with a number of ring sensors that measure the temperature of the hole wall at their respective depths. The temperature increase as depth increases [PS, Jan. '72] is a measure of the continuous heat loss from the moon's interior to its surface.

One lunar surface experiment not attached to ALSEP is the Solar Wind Composition Experiment. This is simply a piece of aluminum/platinum foil unfurled like a sail facing the sun. Small patches of the foil consist of two and three sheets.

The idea is to trap noble gases (helium, argon, krypton) and other particles which make up the solar wind. By better understanding this wind, scientists hope to resolve several competing theories on the origin of chemical elements, the birth of the solar system, and the history of Earth's atmosphere.

Spotting cosmic rays. An experiment unique to Apollo 16 involves a detector consisting of four small plastic, glass, and mineral panels. This detector array will be attached to the lunar module during the trip to the moon, and returned to Earth for analysis. When cosmic rays pass through the detector materials, they leave distinctive tracks that become visible with chemical etching. Scientists may be able to determine the age and chemical composition of cosmic-ray particles originating in deep space and the sun.

Probably the most important activity on the lunar surface will again be collecting geology samples. Their usefulness depends on the precision with which location, orientation, and circumstances of each find are documented by the astronauts.

Taped narration of even minor activities during land traverses, and ample use of hand cameras, will greatly help in sorting out the samples. Special soil tests, where the astronauts dig small trenches and test the bearing strength of the lunar soil, will also help determine the geologic characteristics of the landing site.

Science in lunar orbit. Apollo 16, like the 15 mission, will have a sizable portion of its lunar-science program conducted from orbit. Again, one bay in the service module has been vacated for the sole use of scientific equipment. This SIM bay (for Scientific Instrument Module) accommodates, among other things:

- A 24-inch-focal-length panoramic camera to obtain—from the 60-nautical-mile orbit—stereoscopic pictures of lunar surface details with a resolution of three to six feet. The camera is suspended in a gimbal system that tilts fore and aft to provide stereo coverage as well as no-blur forward-motion compensation.
- A mapping camera with a three-inch cartographic lens to obtain high-quality metric photographs.
- A laser altimeter which, in one of several operational modes, can determine the precise elevation of the area being photographed.
- An X-ray fluorescence experiment using three gas-filled proportional counter-detectors that continuously scan the fluorescent X-ray flux from the lunar surface. This fluorescence is generated by impinging X rays from the sun, and its "signature" varies with the chemical composition of the lunar surface material. The experiment thus provides information on the distribution of the major rock-forming elements on the moon.
- A separate subsatellite that will remain in lunar orbit for several years. One of the most interesting tasks of this subsatellite is to survey the far field of the Earth's magnetopause.

Many satellite flights have shown that the Van Allen Radiation Belt, while appearing "as advertised" in the direction toward the sun, is actually blown out on the opposite side by the solar wind into a "geomagnetic tail." Particle and electrostatic detectors will help provide a clue to the shape of the magnetopause.

Other subsatellite data, combined with samples and data from the Descartes site, should significantly add to our knowledge of the solar system and the universe.

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By DR. WERNHER von BRAUN
NASA Deputy Associate Administrator
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In the late Seventies you'll ride an airliner of a new breed through the skies.

It will fly you about 100 miles an hour faster than today's passenger planes. It will offer you a smoother and quieter ride. On top of these advantages, your fare should be reasonable, because the new craft will be more economical to operate than any airliner in use today.

Good-neighborly features of the advanced airplane will appeal to others besides passengers and operators. Its engines will be smokeless. Outside, as well as in, its sound will be hushed.

NASA, which has pioneered this radical airliner, calls it the Advanced Technology Transport—ATT for short. It also goes by the name of the Mach 1 airliner, because it will cruise at almost Mach 1—the speed of sound or about 660 mph, at cruising altitudes of 35,000 to 45,000 feet.

Dr. Richard T. Whitcomb, who pioneered supercritical wing and wasp-waist concepts, views model of new wing on an F-8.

The Advanced Technology Transport will be "boomless." Its speed will not quite suffice to cause the objectionable sonic boom that supersonic aircraft create as they pass through the speed of sound. But it will far outpace today's airliners. The Boeing 707, for example, lumbers along at Mach 0.84—about 550 mph in layman's language. ATTs will speed as fast as Mach 0.98, or about 650 mph.

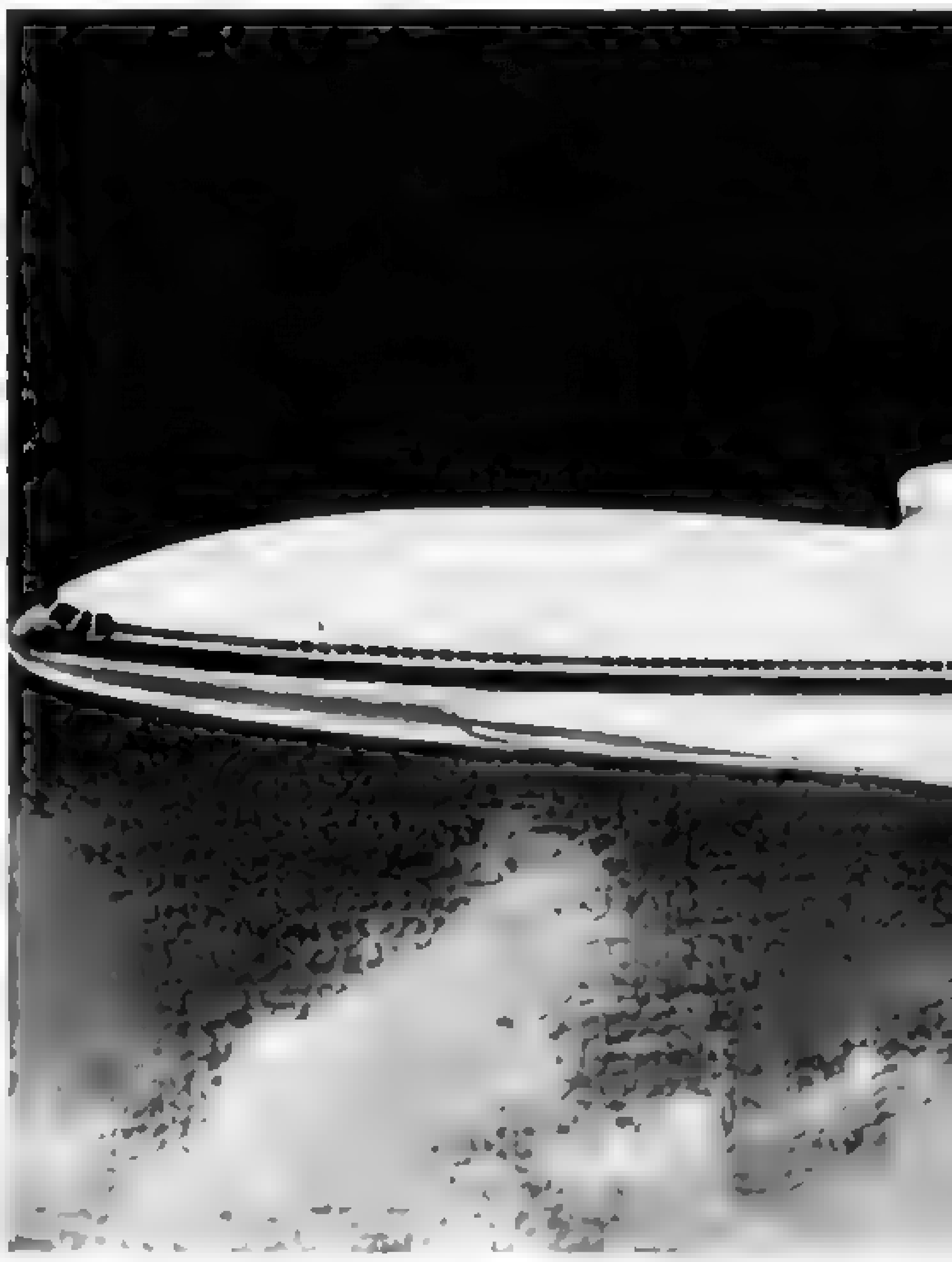
A whole family of ATTs, from 200-passenger airliners of transcontinental range up to 400-passenger transocean versions, is foreshadowed in current studies by NASA and by leading airplane and engine builders under NASA contract. At Mach 0.98 they will clip nearly an hour from a New York-to-San Francisco flight; up to two hours from an ocean crossing.

Higher speed without using more fuel, giving the ATT the economy of more miles per gallon of fuel, comes from two major breakthroughs:

The new supercritical wing. In July 1965, a confidential report announced the discovery of a wonder-working new wing shape, called the "supercritical wing," by Dr. Richard T. Whitcomb of NASA's Langley Research Center.

As a conventional airplane wing approaches the speed of sound, the airflow past its curved upper surface locally becomes supersonic, and a

Conspicuous wasp waist, new to passenger



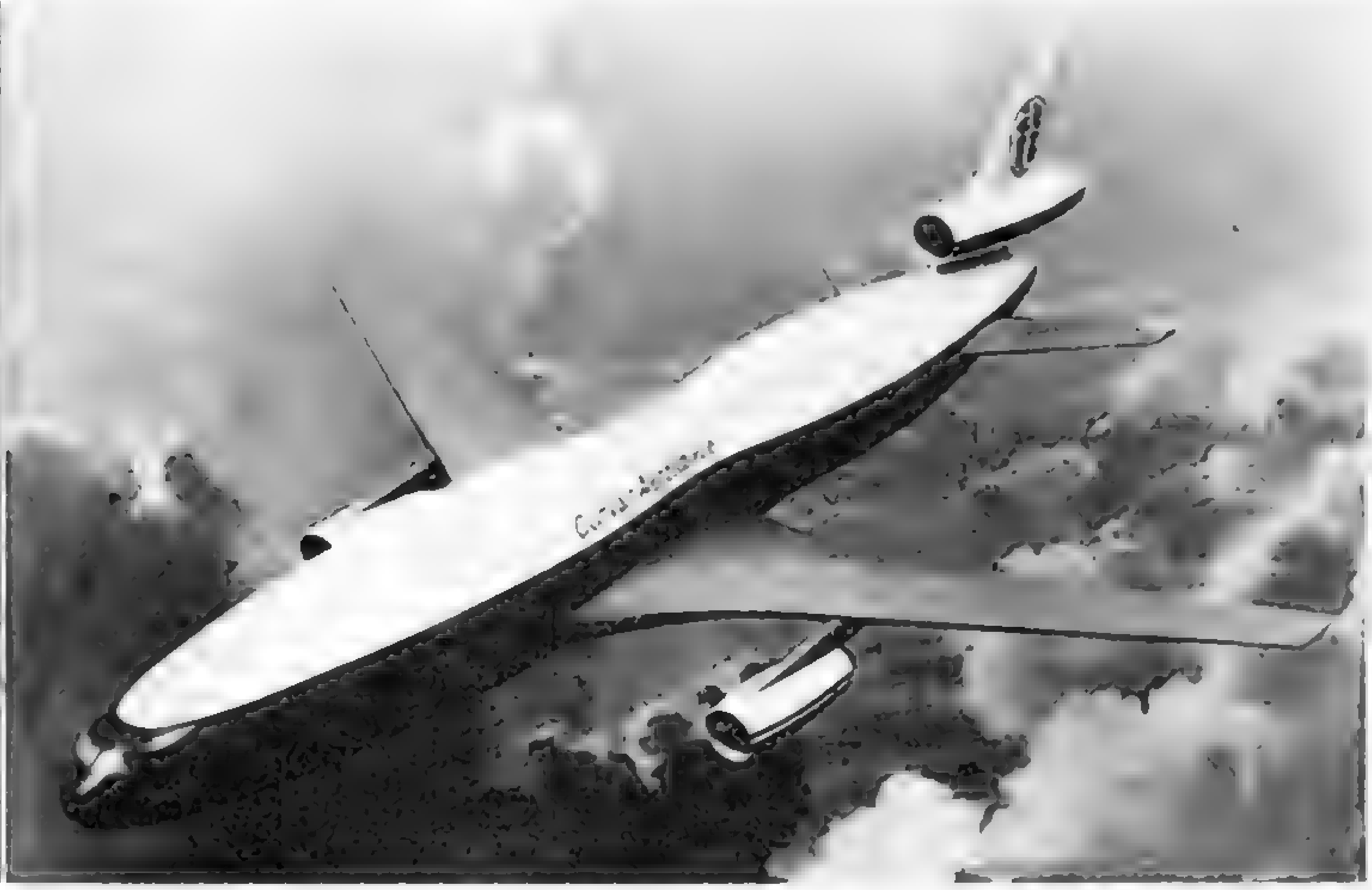
Projected family of Mach 1 airliners may include 400-passenger transocean craft, ex-

shock wave begins to develop there. Beyond this "critical" point, as it is called, there is a precipitous rise in air drag and the engine power required to overcome it; moreover, buffeting fatigues structures and causes discomfort for passengers.

The novel flat-top shape of the NASA supercritical wing delays the onset of these effects. Wind-tunnel tests, between 1965 and 1970, indicated that it promised speeds exceed-

aircraft, is striking feature of NASA's Mach 1 plane. The 200-passenger transcontinental version above is envisioned by Boeing.

emplified by this Lockheed concept, with a range of more than 5,700 statute miles.



Alternative Mach 1 airliner is the design of General Dynamics' Convair Division: a 200-passenger craft with coast-to-coast range of more than 3,400 miles.

ing Mach 0.95 before the drag rise and buffeting began.

Finally the wraps came off, and in early 1971, the new wing's predicted performance was verified in flight tests with a modified F-8 airplane.

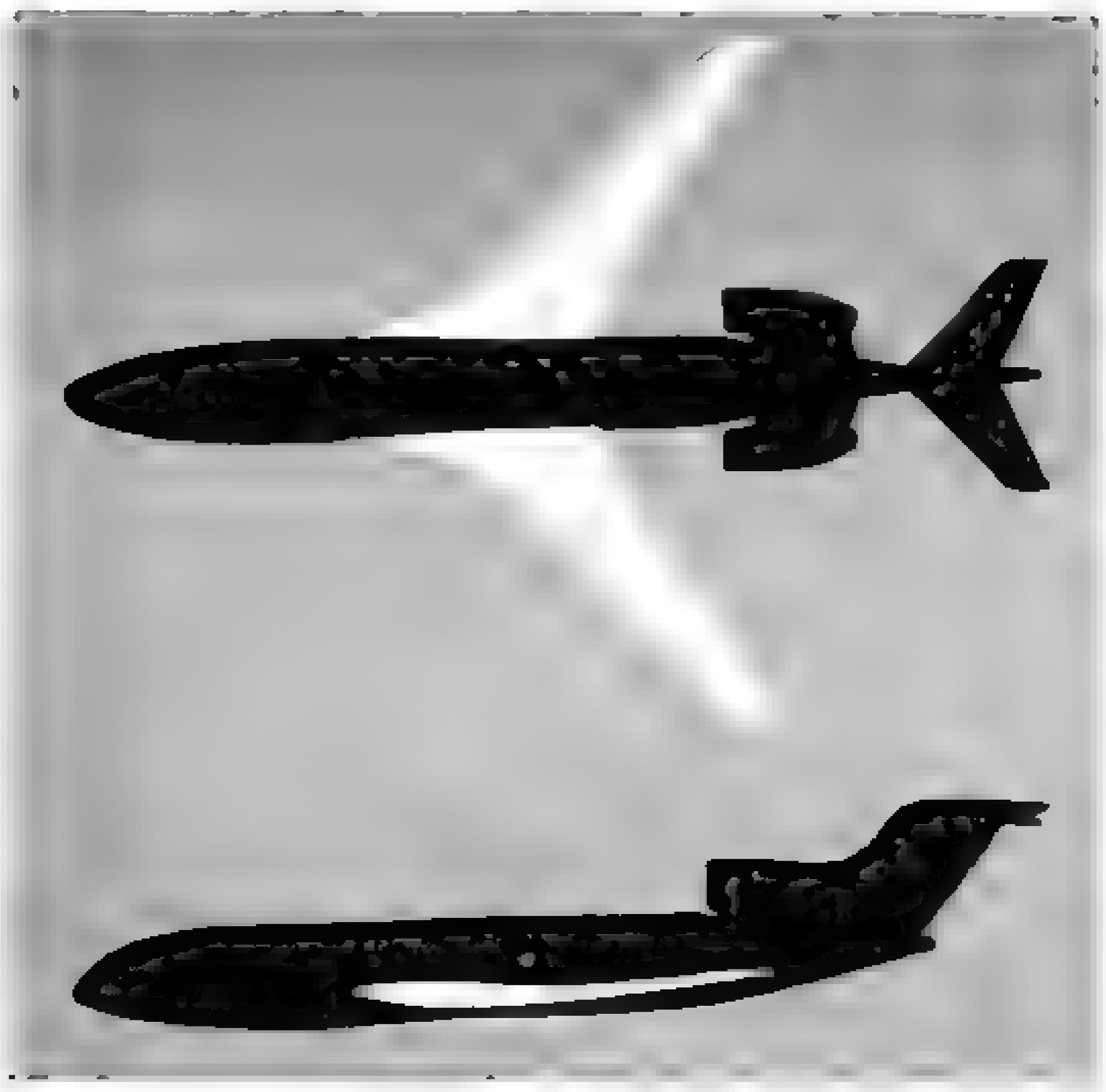
To build an airliner that could take full advantage of the new wing, another major discovery—already contributed by the same researcher, Dr. Whitcomb—had to be applied:

The wasp waist. Most conspicuous innovation of the ATT will be its other breakthrough, the wasp-waist or "Coke-bottle" shape of its fuselage. Like the newer supercritical wing, the wasp waist plays a key role in reducing air drag.

The pinched-in shape stems from a drag-reducing Area Rule that made big aeronautical news when its discovery by Whitcomb was released from military secrecy in 1955. In its simplest or "transonic" original version, the Area Rule works like this:

Take one of our present-day airliners such as the Boeing 707. Determine its drag-producing areas from nose to tail by taking slices, salami fashion, at one-foot intervals. You'll find the cross-sectional area increases smoothly up to where you get to the full diameter of the cylindrical body. Here it levels off.

But as your wandering salami knife strikes the engine intakes and the



New supercritical wing, an innovation to be incorporated in the coming Mach 1 airliner, is shown above being installed for flight trials on a modified Navy F-8 jet plane at NASA's Flight Research Center, Edwards, Calif. Drawings at left reveal novel shape of the drag-reducing "flat-top" wing as viewed from top and side.

wing root, the drag-producing cross section suddenly shoots up again. On a graph of step-by-step areas, it forms an ugly bump. This bump is by no means desirable for a Mach 0.84 plane like the Boeing 707. For a Mach 0.98 transport it would be disastrous. To keep the drag at that speed within acceptable limits, that bump has to be reduced or eliminated.

The solution is to tighten the belt of the airplane's body, enough to offset the excess cross-sectional area of wings and engine nacelles. And what you get is the wasp waist.

The first wasp-waisted aircraft were Air Force and Navy fighters of 1954. The B-58 Hustler bomber of 1956 was another example. While many later supersonic aircraft look as if their designers had never heard of the innovation, the reason is simple:

Benefits of the original Area Rule's wasp-waist shape are limited to the transonic range of speed—about Mach 0.9 to Mach 1.2. For faster craft there now are more-complex "supersonic" forms of area-ruling, which do not lead to a prominent wasp waist, but to subtler refinements of shaping. The wasp waist, however, remains ideally advantageous for a plane that lingers near Mach 1. The ATT, first passenger plane that just fits this description, will therefore have it.

This "waisting" raises another question. A very convenient way of adapting airliners of the same generic breed to airlines' widely differing requirements is the method called *stretching*.

By adding constant-diameter body sections fore and aft of the wing, higher-capacity models of a current transport can be spun out of the original airplane with relative ease. We all have seen the stretched DC-8s and the stretched Boeing 727s.

The capability to stretch a basic airplane design will be as important for the breed of Mach 1 airliners as it is for today's birds. Obviously, with a carefully sculptured area-ruled Mach 1 transport, thorough wind-tunnel studies must precede and support design stretchouts to avoid unacceptable bumps.

Showcase of advanced features. The ATT aims at much more than higher cruising speed. It will be a showcase of the most advanced technology of all kinds that can be crammed into an airplane. There are a number of innovations it will incorporate.

- Engines will not smoke at any power setting. Carbon monoxide and unburned hydrocarbons in the exhaust will be greatly reduced, diminishing air pollution.
- Noise will be lowered far below stringent Federal standards for new aircraft, without a noticeable effect on operating cost. Further dramatic quieting, by improved engine design and acoustic treatment, looks possible with only a modest increase in operating cost.

In a world extremely sensitive to the words "pollution" and "environment," these competitive advantages alone may often be decisive.

- Composite materials—like fiberglass in principle, but using novel recipes such as boron fibers embedded in a plastic matrix—will find extensive use and will reduce structural weight by 10 percent or more.
- A technique called "fly-by-wire," which has become a must in manned space flight, will make airplane controls responsive to an ATT pilot's gentle touch. By way of a computer, his pedal and yoke deflections go to power-steering actuators that move the airplane's control surfaces. The same computer accepts additional command signals from instruments such as an angle-of-attack meter, an airspeed indicator, an altimeter, and an accelerometer.

Extensive flight testing has shown that the more-elastic response of fly-by-wire to gusts and turbulence will offer you a smoother ride. It also extends the "fatigue life," and thus the revenue-producing life, of the entire airplane structure.

- At terminal airports, steep climbouts and landing approaches will greatly reduce the ground area affected by low overflights—a desirable goal, even with drastically reduced engine noise, in densely populated localities. Today an airplane making an instrument landing, under conditions of low ceiling and limited horizontal visibility, must follow the shallow 2½-degree glide slope provided by standard sys-

[*Continued on page 132*]

Airborne on new wing, F-8 confirms promise it showed in wind-tunnel tests. For more experiments, addition of side fairings will give test plane a wasp waist.

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Popular Science

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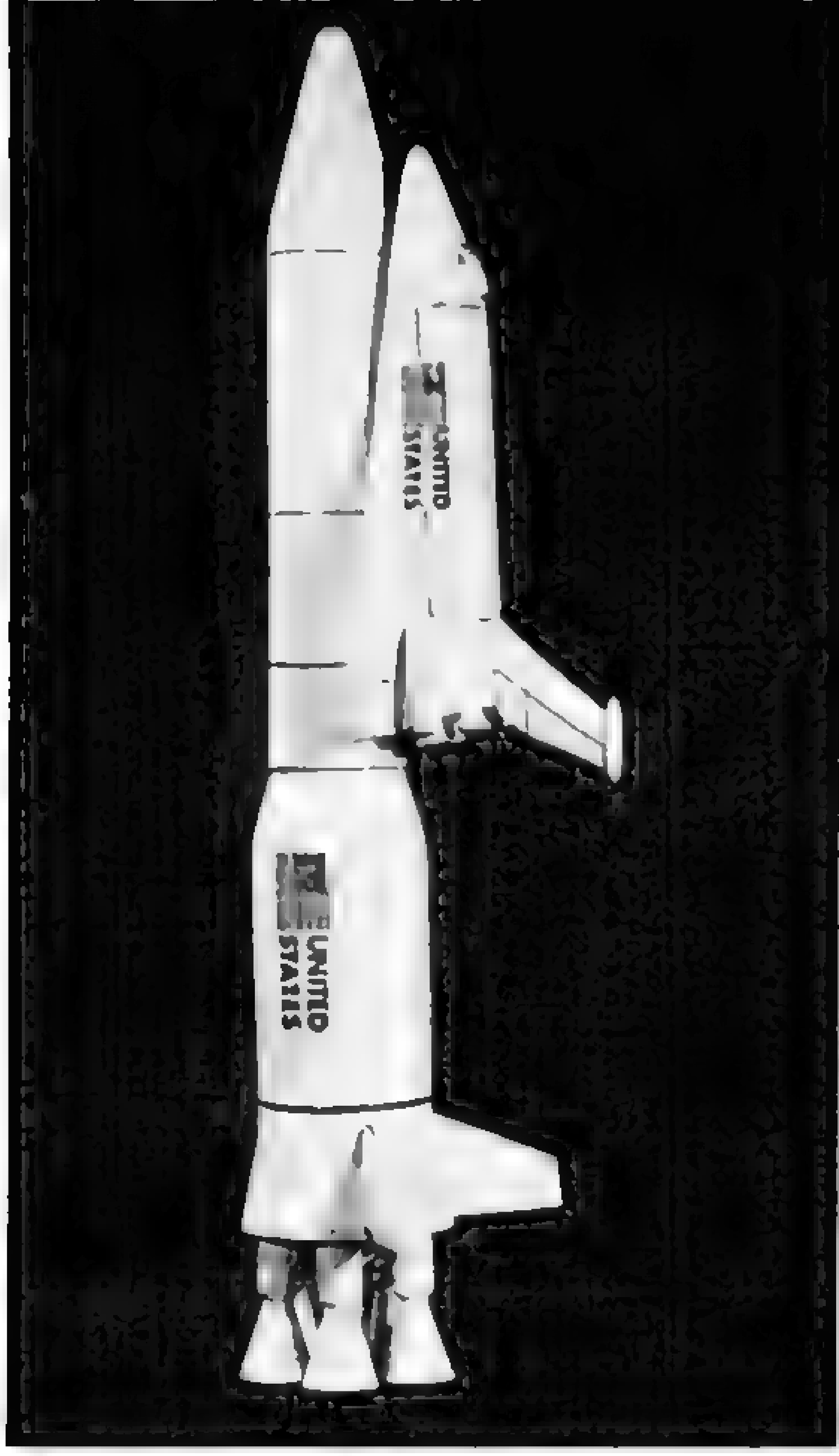
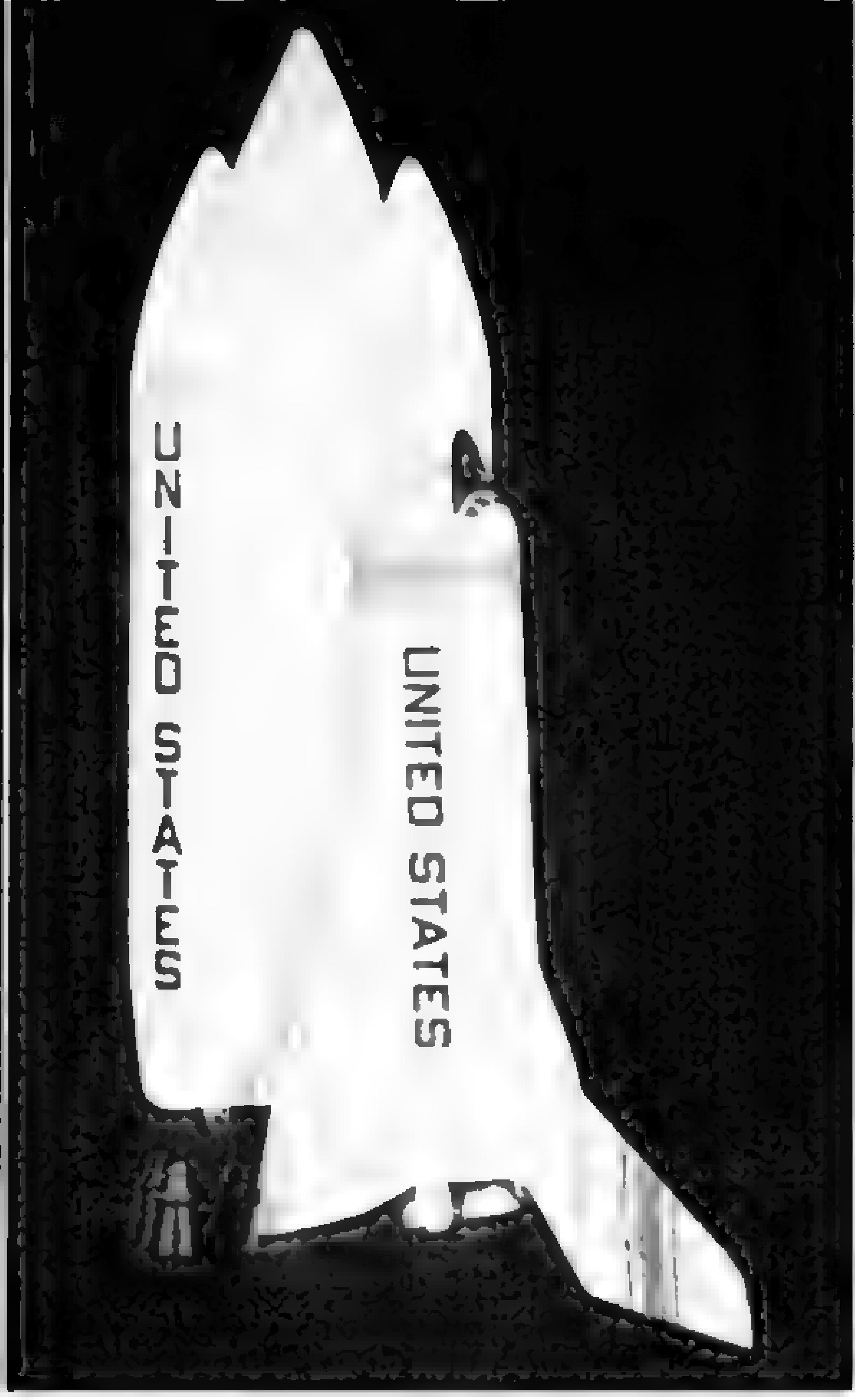
Sneak Preview!

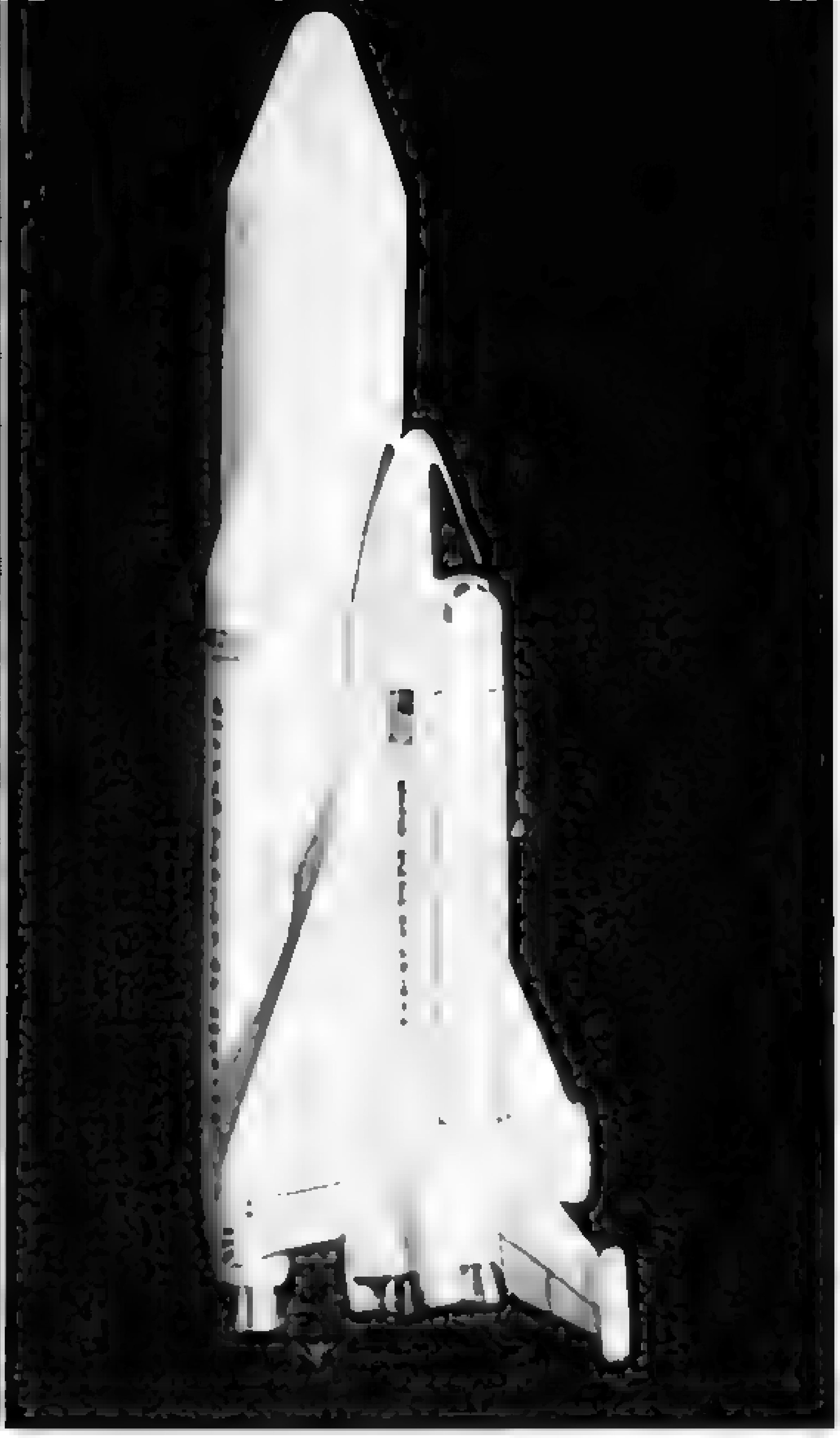
GM's NEW ROTARY ENGINE for Chevy's '74 Vega



After accelerating orbiter and its huge fuel tank to Mach 4, six-engine booster in this McDonnell Douglas design drops away.



In a Grumman design, two pressure-fed, liquid-fuel boosters are mounted on orbiter's fuel tank, which is ejected once in orbit.



Solid-fuel boosters would be jettisoned 35 miles up after burning in parallel with orbiter engine. North American Rockwell design.

SPACE SHUTTLES GET THE GREEN LIGHT

By WERNHER von BRAUN
NASA Deputy Associate Administrator
PS Consulting Editor on Space

NASA is now moving quickly to develop a reusable space transportation system. Here's how we'll put it to use after Apollo

At a special Kennedy Space Center launch complex sometime in the late seventies, massive high-bay hangar doors will slide open. Slowly, ponderously, an odd-shaped space vehicle will emerge on a treaded crawler transport and inch toward a nearby launch pad.

The vehicle, the nation's first reusable space transportation system, is moving rapidly into the development stage following President Nixon's January endorsement of the space-shuttle concept. The President said, "The space shuttle will give us routine access to space by sharply reducing costs in dollars and preparation time."

This multipurpose shuttle, which will take off like a rocket, fly in orbit like a spaceship, and land like an airplane, will replace almost all present expendable launch vehicles. It will carry into space most of the nation's payloads, scientific and applications, manned and unmanned, civilian and military.

Towering as high as 175 feet—about 17 stories—the space shuttle will weigh some 4.7 million pounds when fueled for launch. It will have a delta-wing, airplane-like orbiter about the size of a DC-9 sidestrapped to its disposable liquid-hydrogen/liquid-oxygen tank.

It will also have a booster, and depending on the booster configuration selected this spring, the launch sequence will vary slightly. Using one competing design as an example (left photo above), here is how a shuttle mission would develop.

In this version, an unmanned, liquid-fuel booster is attached to the tail end of a large propellant tank to which the delta-wing orbiter is piggybacked. The booster's propellants—kerosene and liquid oxygen—would be fed into six one-million-pound-thrust rocket engines by about 300 pounds of pressure in the tanks.

A crew of two will pilot the orbiter, which may also carry two flight engineers to check out unmanned satellite payloads and deploy them in space. The orbiter is powered by three 470,000-pound-thrust high-pressure engines, fed from the large liquid-hydrogen/liquid-oxygen tank to which the orbiter is side-strapped. Carrying these propellants outside the orbiter provides space for a roomy cargo bay: 15 feet in diameter and 60 feet long—big enough to accommodate a Greyhound bus. Payloads up to 65,000 pounds will be possible.

Manned-booster concept abandoned. After blast-off, at an altitude of 35 to 40 miles and moving at about Mach 4, the booster is jettisoned. It follows a ballistic flight path and, supported by a cluster of parachutes, splashes into

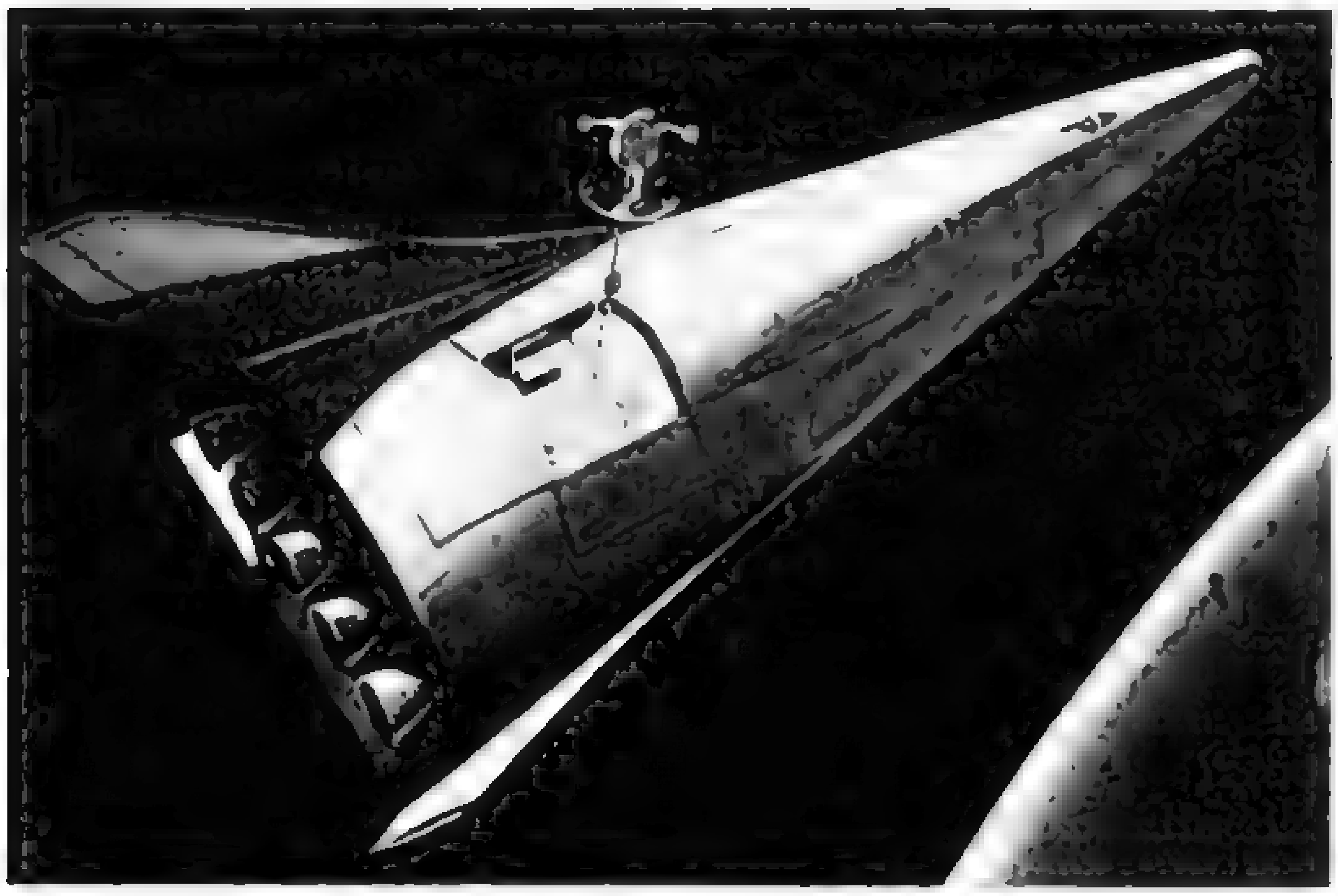
Continued

the ocean 200 to 300 miles downrange. Earlier concepts envisioned a manned 747-size booster, to which a manned 707-size orbiter would be side-strapped. But the fly-back booster concept [PS, July '70], with its prohibitive development price tag, has now been abandoned in favor of the unmanned ballistic booster that can be recovered, refurbished, and reused.

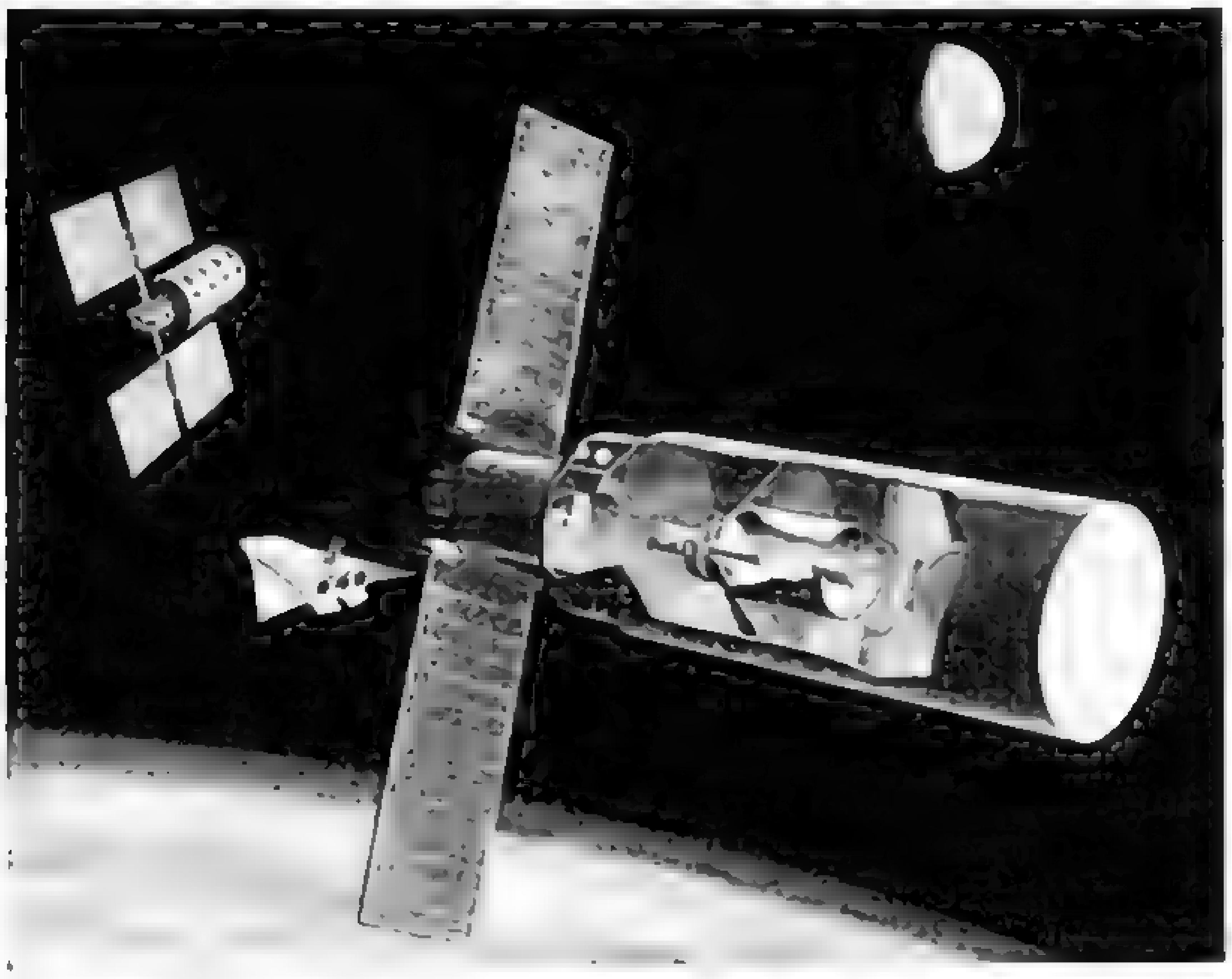
The orbiter, using its three engines, will achieve orbit with its huge propellant tank still strapped beneath its belly. Here the tank will be detached. It can be pushed back into the atmosphere with a small rocket; reentry can be timed so that debris surviving the fiery trip falls into remote ocean areas.

Instead of a single booster pushing against the orbiter's external propellant tank, study contractors have also looked into the feasibility of two parallel-mounted, pressure-fed liquid boosters (middle photo, preceding page). Even solid-fuel boosters, expendable as well as reusable, have been studied (right photo).

Depending on mission requirements, the orbiter will remain in orbit from a week to 30 days. Then the crew will pilot the orbiter back to Earth for an airplane-type landing on a runway constructed near the launch complex. Enough fuel for orbital maneuvers and reentry is carried in the fuselage. From its reentry point, the orbiter will



Activation crew for satellites would deploy antennas and solar panels. Before releasing satellite from extension arm to shuttle, they would confirm good data reception at ground stations.



Astronomical modules illustrated could be placed in orbit by separate shuttle orbiters. Programed to operate automatically for weeks, they would be visited periodically for film removal.

have a cross-range maneuvering capability of 1,100 miles.

Even if we allow $2 million for each orbiter fuel tank lost on a mission, total flight cost, with reusable liquid-fuel boosters, is estimated at $7.7 million. With solid-fuel boosters, it may run $10 million per flight, but development cost would be lower. Even $10 million is far less than the cost of today's expendable launch vehicles (except the little Scout), and yet the shuttle's orbital payload capability of 65,000 pounds exceeds all except the giant Saturn 5. An estimated $5.5 billion over a six-year period will be needed to develop the shuttle system.

Manned or unmanned space flight? Saving in transportation cost, however, is only one of the shuttle's promised blessings. Unmanned satellites can be repaired or serviced by men in space, or returned to Earth for refurbishment, updating, and reuse. Shuttles will greatly reduce satellite mortalities: A high percentage of automated satellites fail immediately after injection into orbit. Antennas fail to unfurl, sensor systems may not respond to ground command, or batteries may run down in a few hours when solar-cell arrays deploy improperly.

With the shuttle, user agencies may seriously consider buying a satellite "FOB orbit." The supplier would send an activation crew along when the shuttle carries the satellite into orbit (see drawing, left).

The old argument over manned vs. unmanned space flight should thus simply disappear. With manned, reusable shuttles providing cheaper transportation into orbit than any other system, the shuttle will corner the space-transportation market.

But man's future role in space will far exceed his contributions in service and maintenance. The shuttle's huge cargo compartment can accommodate Research and Applications Modules (RAMs)—house-trailer-size, pressurized cylinders developed for research and exploratory missions.

Trimming costs with standard equipment. RAMs will become a modular home for a variety of space laboratories. (No one has yet suggested running an entire research laboratory by computer!) The shuttle's ample payload capability will free researchers from weight constraints, while the benign shuttle environment—low acceleration, low vibrations, no temperature extremes—along with man's presence in the RAM, will permit extended use of standard laboratory equipment.

Today, a sophisticated, automated spacecraft costs up to $30,000 per pound. Standard laboratory equipment placed in a RAM will cost an average of as little as $100 per pound; specially constructed, highly miniaturized equipment so expensive to develop won't be necessary.

Missions of this kind may be flown in the "sortie mode": Several non-astronaut scientists would participate in a 10-day flight. During this time they would finish their carefully prepared measuring program involving astronomy, meteorology, oceanography, Earth resources, medical studies, zero-gravity processing techniques, or just basic physics and chemistry.

After obtaining their data, the scientists would return to Earth with the equipment, analyze the data, and write their papers. The RAM would then be refitted for the next sortie mission. For astronomical missions, where precise telescope alignment is essential, the RAM may even be disconnected from the orbiter to float freely nearby (see bottom drawing at left).

Test flights should begin in 1976, manned orbital test flights in 1978, and an operational shuttle should be ready before 1980.

[Note: At press time, NASA announced it has decided to use solid-fuel rockets to launch space shuttles.]

Popular Science

THE What's New MAGAZINE

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SPACE SUITS—from Pressurized

From high-flying aviators' earliest pressure suits stemmed moon gear for those record-breaking lunar jaunts that you watched on TV

By DR. WERNHER von BRAUN
NASA Deputy Associate Administrator
PS Consulting Editor on Space

Two relaxed and exuberant spacemen set all-time moonwalking records last April. In three treks on successive days, Apollo 16 astronauts Young and Duke spent 20 hours and 14 minutes exploring the moon—nearly two hours longer than Apollo 15's previous mark. Their longest trip, of 7 hours 23 minutes, bettered Apollo 15's by 11 minutes.

Both Apollo 15 and 16 used improved new space suits and backpacks, carrying enough oxygen and cooling water for a nominal seven-hour sortie, against four hours in all preceding moon-landing missions. The suits' enhanced flexibility, plus lifts from lunar-roving vehicles, so eased the astronauts' exertions—and hence their oxygen and cooling needs—that left-over amounts of their carefully monitored "consumables" repeatedly gave them a bonus of precious minutes beyond the new seven-hour rating of their gear.

The evolution of space suits has come a long way since 1934 when Wiley Post, pioneer globe-circling pilot and discoverer of the jet stream, ordered a pressure suit for an attempt to break the world's altitude record of 47,532 feet.

Topped by a diver's helmet, his inflated suit of heavy rubberized fabric was designed to protect him from the near-vacuum of the upper atmosphere. Although Post set no officially recognized new mark, history does credit him with creating the world's first practical pressure suit, now a museum piece at the Smithsonian Institution.

Granddaddy of space suits (above), worn by Wiley Post in 1934, was made to his order by Goodrich for airplane altitude-record attempt. Diver's helmet topped it.

High-flying World War II airmen wore pressure suits as safeguard if bullets pierced pressurized cabins. This "Strato-Suit" was a Goodrich version of 1945.

By World War II, stratosphere flying had arrived, and Air Force and Navy airmen wore pressure suits to protect them when bullets punctured their pressurized cabins. An example was the illustrated "Strato-Suit," with a helmet of transparent plastic, developed in 1945 for the Air Service Technical Command. The stiff inflated suits, like Wiley Post's, offered little more mobility than a straitjacket.

America's first true space suit came into being for our Earth-orbiting Mercury astronauts of 1962-63. They needed a suit with enough mobility to handle controls and throw switches. Pressure suits were more flexible by then, and a Navy Mark IV suit was suitably modified. Along with a life-support system in the spacecraft, it would provide the wearer with a livable atmosphere if the cabin lost pressure—say, from a leak, or puncture by a meteoroid. Actually, no such emergency arose.

The why of space suits. Just what would happen to an unprotected human being in the zero-pressure vacuum of space? Human lungs collapse at a pressure not far below the minimum acceptable for a space suit, about 3½ pounds to the square inch. Even before pressure drops so low, accidental decompression of a cabin with an airlike atmosphere releases bubbles of nitrogen gas in the blood, causing an incapacitating or fatal attack of the dreaded decompression sickness that divers call "the bends."

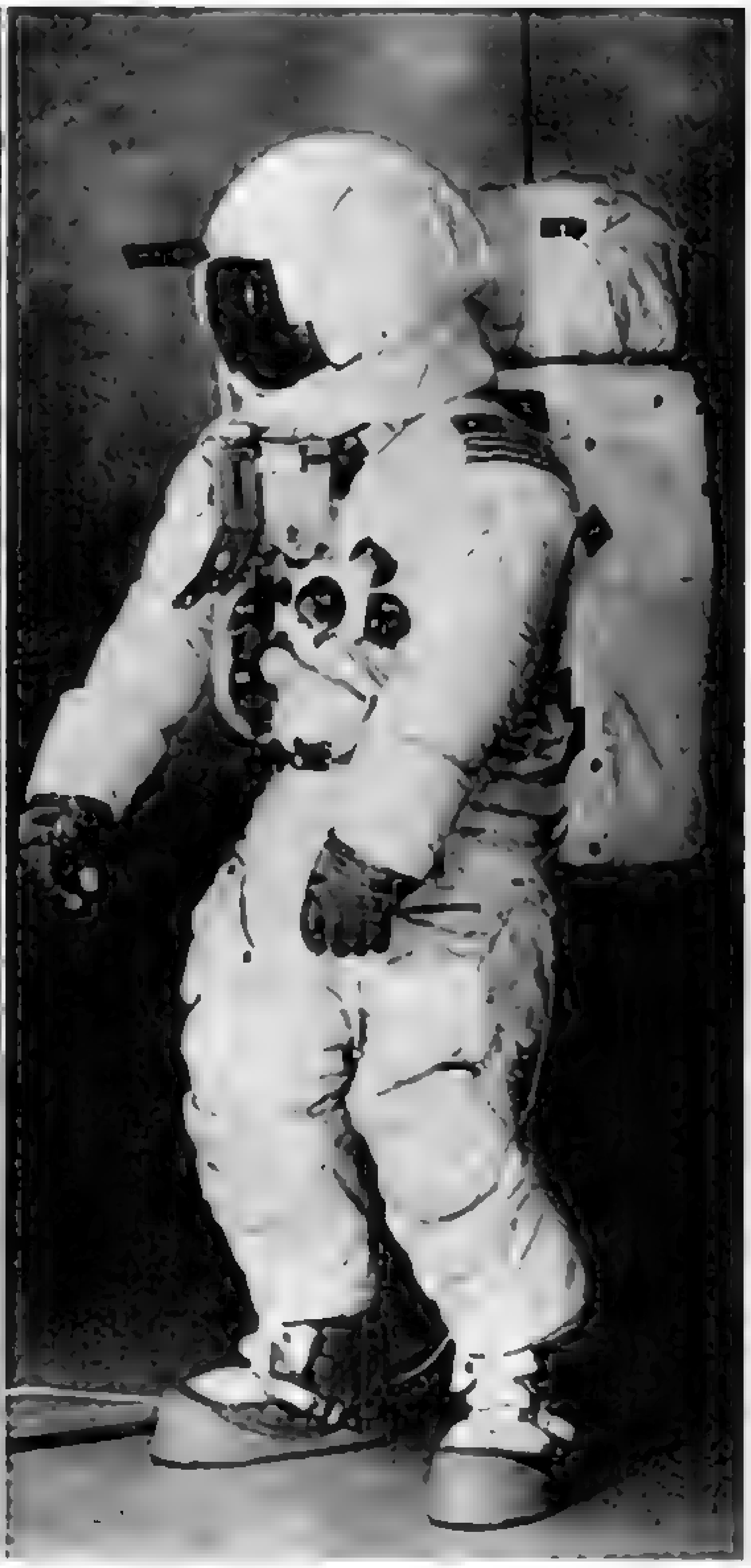
[The peril of pressure loss was tragically demonstrated only last year when three Russian cosmonauts, after setting a 19-day endurance record in a Salyut space station, were found dead in a Soyuz spacecraft that returned them automatically to Earth. As in current U.S.S.R. and U.S. reentry procedure, they had not been wearing space suits—and a Soviet investigation showed they died suddenly from rapid loss of cabin pressure, apparently through a faultily sealed hatch.—*The Editors.*]

Suits for spacewalking. Gemini, the second phase of our manned space-flight program, had more ambitious objectives than Mercury. For one thing, NASA wanted to find whether an astronaut could emerge from the two-man spacecraft and perform useful work outside, protected only by his space suit. This "extravehicular activity" (EVA for short) advanced the role of the Gemini suit from a backup to a prime system.

Prison to Mini-Spacecraft

America's first true space suit, for Mercury astronauts of 1962-63, was intended to save them if atmosphere of craft's cabin should escape. It never had to.

Gemini suit served first U.S. spacewalkers in flights of 1965-66. Oxygen from spacecraft reached astronaut working outside via trailing hose of umbilical line.



Apollo suit for moonwalking sets an astronaut free to roam over lunar surface. Backpack supplies oxygen and water-cooling to offset intense heat of blazing sun.

It demanded more mobility, better thermal protection, safety from micrometeoroids whizzing by in space. Since EVA required depressurizing the cabin to open the hatch, it needed an independent life-support system, which, however, could be in the cabin and supply oxygen to a spacewalker through the same umbilical line that carried the intercom cable.

Then came moonwalking. For NASA's lunar-landing program, space-suit requirements grew truly formidable:

- Thermal protection and control had to cope with extremes from 250 degrees above zero Fahrenheit to 250 below, during lunar day and night; and with the varying metabolic heat output of a moonwalker at rest, or strenuously exerting himself to

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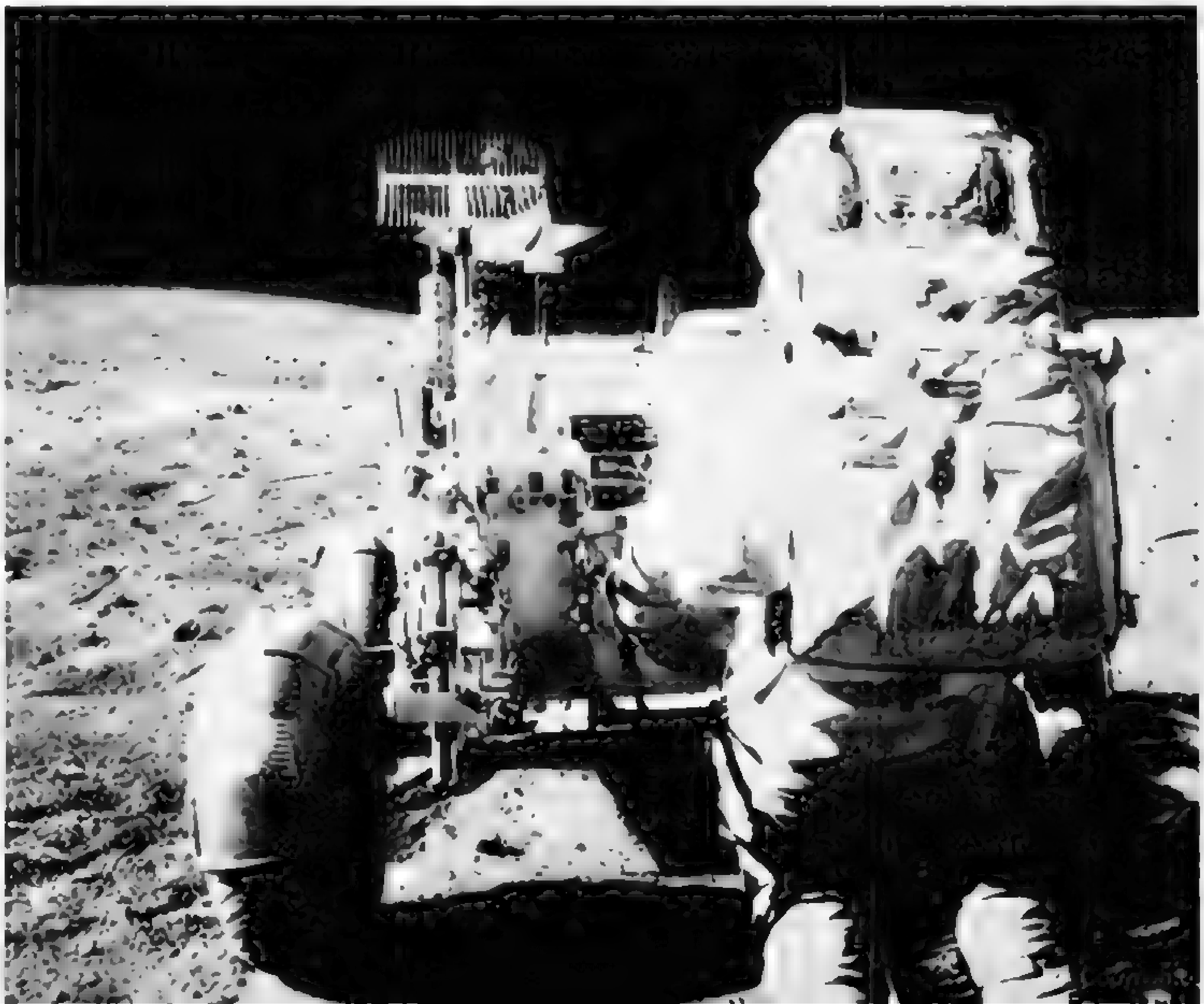
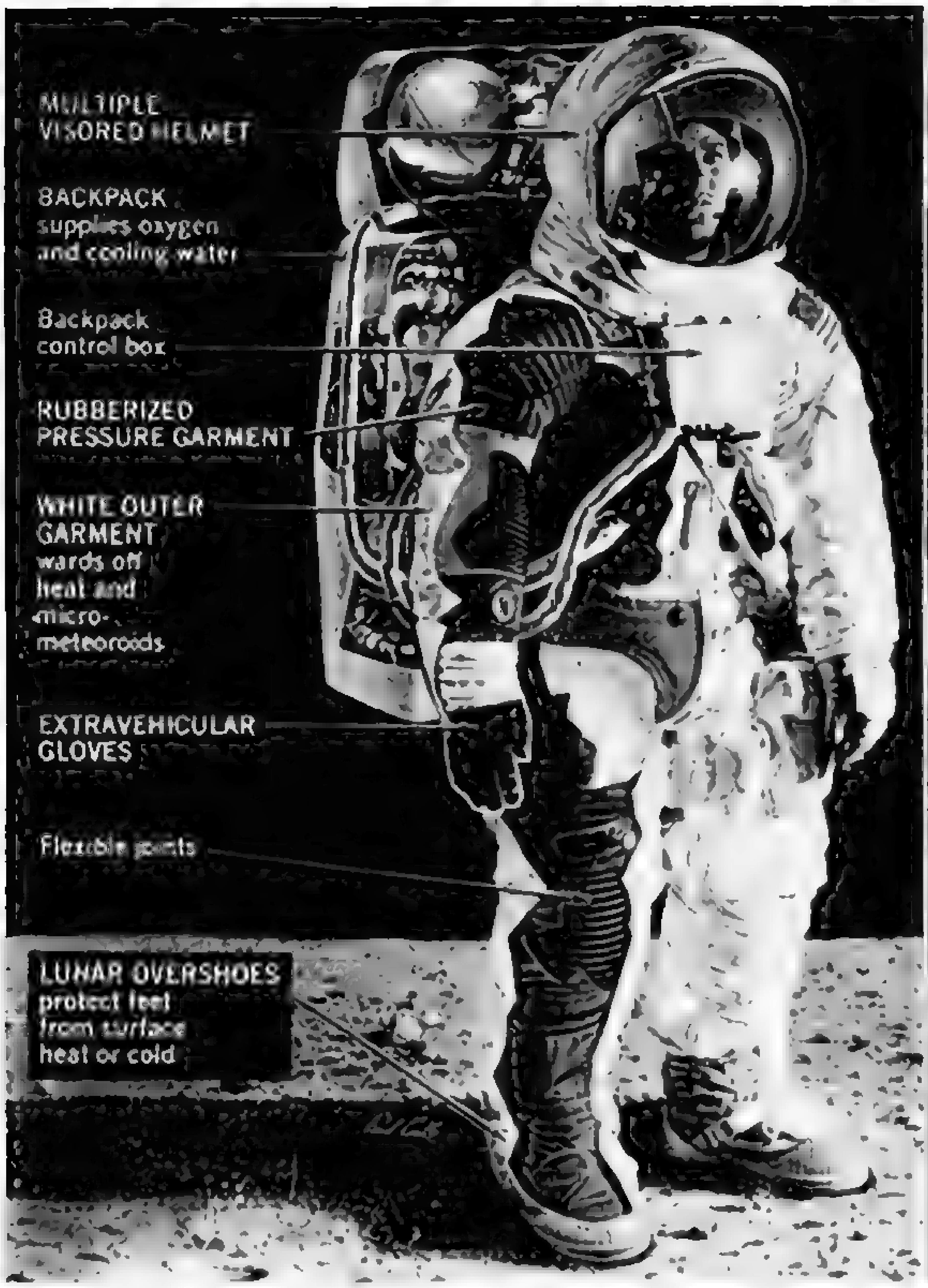
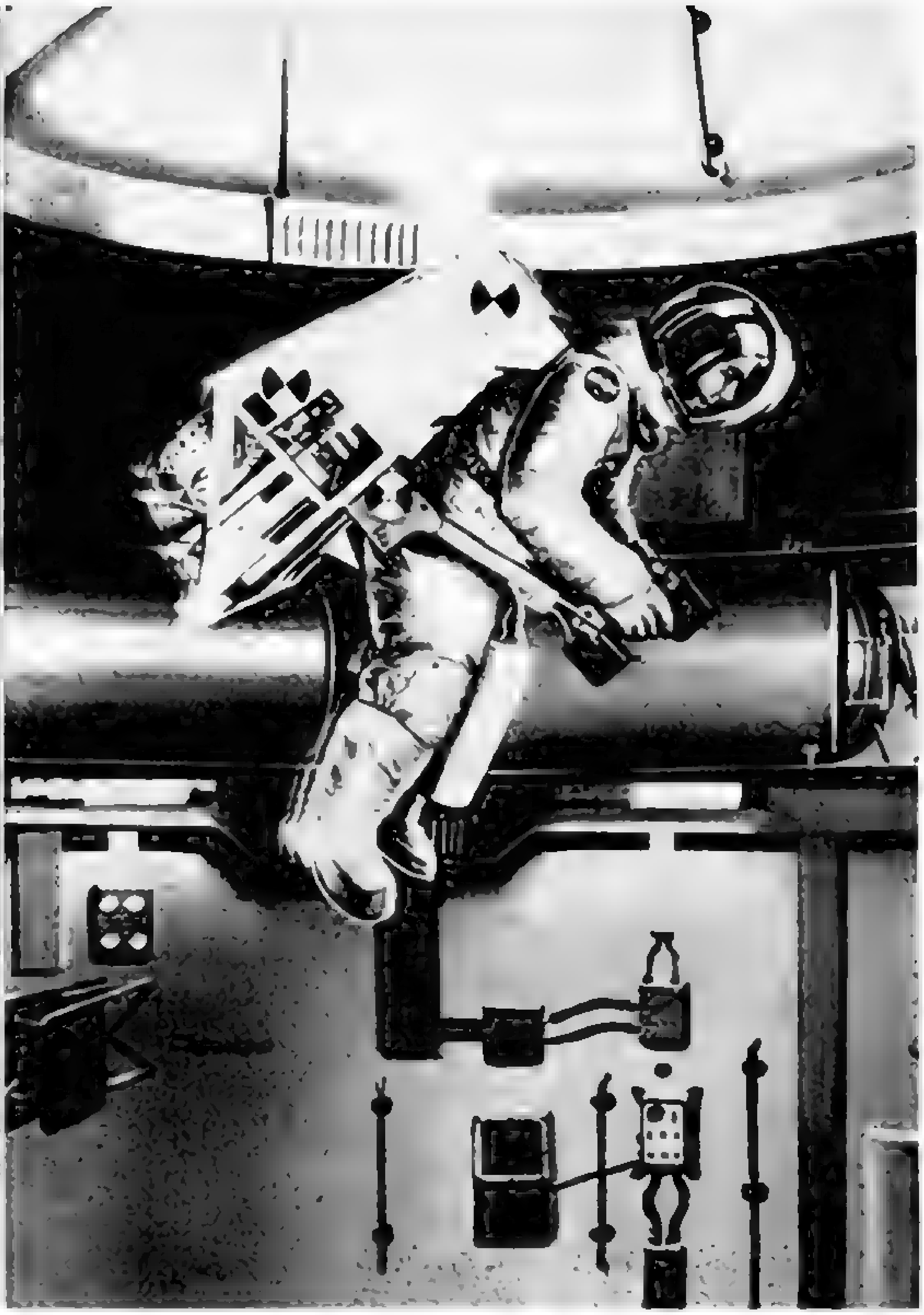


Apollo 16 commander John W. Young returns to moon car after one of stops on the mission's longest moonwalk, which set new record of 7 hours, 23 minutes



Cutaway view of latest-model Apollo suit and backpack reveals some of the principal components of the gear and their purposes.



Coming next: "outboard motors" for space suits. This backpack, due for trial inside Skylab as above, propels wearer with jets.

"Snoopy Hat," inside space-suit helmet, has twin mikes and earphones for two-way communication by radio. Wearer above: Neil Armstrong, first man on the moon.

Flexible new version of Apollo suit—shown at right without white outer garment, to reveal joints—enables moon explorer to bend or kneel to grasp specimens.

climb a lunar hill or wield a tool.

- The astronaut had to carry his whole life-support system on his back—plus an emergency system, in case the prime one failed.
- Radio communication was required between astronauts, and between the astronauts and Earth.
- Suits had to be rugged enough to withstand abrasion by lunar rocks—and, later, to tolerate a bumpy ride in a moon vehicle.
- Finally, astronauts had to be able to don and doff their gear in the confined quarters of the Lunar Module, for vitally needed sleep between arduous excursions outside.

The result was the Apollo suit and backpack—amounting to a spacecraft that, after being "boarded" by an astronaut, could walk upright.

A pressure garment, to which helmet and gloves are attached, forms the central element or "capsule" of the suit. Beneath it, an Apollo astronaut wears water-cooled underwear—a sort of open-mesh Long John, in which cooling water circulates through a network of plastic tubing. A waste-management system provides a built-in "John" during extended trips on the moon.

[*Continued on page 121*]

Space Suits—from Pressurized Prison to Mini-Spacecraft

[Continued from page 64]

Outermost comes a white "overcoat" for protection against heat and micrometeoroids—grain-of-salt-sized particles hurtling down at thousands of miles an hour. Abrasion-resistant cloth reinforces knees, elbows, and shoulders.

In the backpack, cool oxygen circulating through the suit is reconditioned for reuse, and replenished as needed from a high-pressure tank. Cooling water flows through a "sublimator," a sort of metallic sponge in whose pores the water comes in actual contact with the vacuum outside and freezes. Evaporation of the ice into the vacuum chills the water behind it, and maintains any desired temperature in the suit.

For communication the astronaut wears twin mikes and earphones, in his "Snoopy Hat"—more elegantly, a space-suit communications cap—under his helmet. The radio antenna is on his backpack.

Fortunately for the astronaut, the weight of the suit and backpack on Earth (originally totaling 183 pounds) shrinks in the moon's weak gravity to one-sixth of that amount.

With succeeding moon landings, this Apollo outfit has gone through an evolution of its own.

How Apollo gear has changed. The biggest advance came when brief, hurried excursions afoot on the moon gave way to extended, carborne expeditions. Apollo 11 astronauts ventured forth for less than three hours; those of Apollo 12 and 14, for two sorties of about four hours apiece. Current three-day lunar stays, with a trio of excursions nearly twice as long as early ones, took more than revamping the Lunar Module to bring along augmented supplies.

The Apollo suit was remodeled. More oxygen, at higher pressure, went into the backpack. Increased supplies of cooling water and other "consumables" were added. That set the stage for the three long-duration expeditions that began with Apollo 15, continued with Apollo 16, and will end the Apollo program this December with Apollo 17.

A new waist joint, added to existing neck, shoulder, hand, and leg joints, did wonders for the 18-layer Apollo suit's flexibility. With its aid, Apollo 15 and 16 astronauts could sit down for a ride in their lunar roving vehicle, and could stoop to grasp lunar specimens retrievable before only with long-handled tongs or scoops. Space-suit designers were still far from their ideal of "nude-body mobility," but they were on their way.

From the first, the Apollo gear had a backup oxygen-supply and cooling system. If the regular one should quit, an emergency oxygen-purge system would release a blast of cool oxygen through the suit, allowing 30 minutes of grace for a fast retreat to the safety of the Lunar Module. It was, of course, outrageously wasteful of oxygen.

Apollo 14 introduced a modified plan—a "buddy" system enabling an astronaut in trouble on the moon to share his companion's cooling water. A connecting pair of flexible hoses, to make the hookup if need be, was carried on Apollo 14's two-wheeled utility cart and on the Apollo 15 and 16 lunar-roving vehicles. Thus relieved of its emergency-cooling function, the oxygen-purge system's breathing gas would last $1\frac{1}{4}$ hours, during return from a much greater distance.

Numerous other refinements included a container inside the helmet to refresh an astronaut with a sip of water or orange drink during his labors. Telling which was which of two helmeted moonwalkers baffled even NASA viewers until red arm and leg bands were added to the mission commander's space suit.

Apollo Command-Module Pilots, who do not land on the moon, need no lunar backpacks—but Worden and Mattingly, of Apollo 15 and 16, did use extravehicular suits. They made the world's first deep-space EVAs, between the moon and Earth, to retrieve films of the moon from panoramic and mapping cameras in a bay on the outside of the Service Module.

What's ahead? Definitely, future space suits are going places. If it taxed your imagination to think of the Apollo suit as a "spacecraft," consider space suits with self-propulsion gear attached, due to be tested under zero gravity inside our coming Skylab space station in 1973.

One trial hand-controlled model propels a suited astronaut with nitrogen jets, as pictured in an accompanying illustration. Another has foot controls and leaves hands free, for assembling structures or making repairs in space—likely future uses for these "mini-spacecraft."

Certainly our need for space suits will not end with Apollo. Skylab itself, for example, calls for EVA to recover, through an air lock, films of the sun made by its solar observatory. Missions of suited-up spacemen for jobs like tending Earth satellites will multiply with advent of the space shuttles planned for the late 1970s. It looks as if the story of the space suit's evolution has hardly more than begun.

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Popular Science

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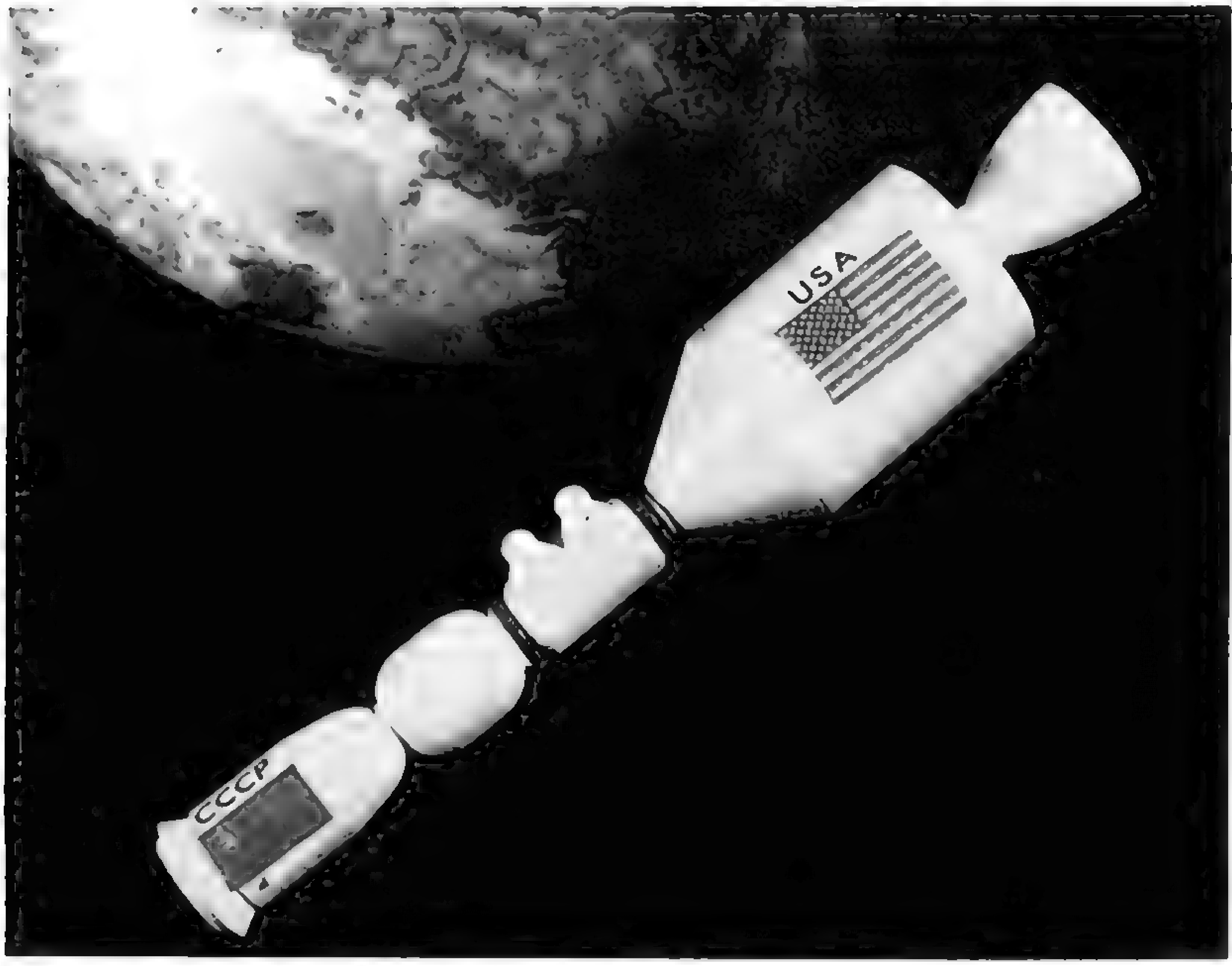
How We'll Team Up with the Russians in Space

By
WERNHER von BRAUN
PS Consulting Editor, Space

Linking up an Apollo and a Soyuz in orbit, just announced for 1975, may open the way to space rescues, international space flights, and possibly even a U.S.-Russian manned voyage to Mars



First US-USSR space docking is previewed by NASA model. Linked in Earth orbit, left to right, are Russian two-segment Soyuz spacecraft; new Docking Module; and American Apollo spacecraft.

The United States and the Soviet Union, rivals in space flight for 15 years, have decided to carry out their first joint manned mission in history. Scheduled for 1975, an exciting project to join an American Apollo and a Russian Soyuz for two days in Earth orbit is the highlight of an agreement on space cooperation signed by President Nixon and Premier Kosygin at the Moscow summit meeting last May.

Planned during the Apollo-Soyuz mission are visits by the spacemen from one ship to the other; and some joint scientific experiments, probably simple, still to be chosen. Mainly, however, the mission will be a practical flight trial of an extraordinary new piece of space equipment called a Docking Module—a combination docking-system adapter and air lock, which will permit linking U.S. and Russian manned spaceships despite their incompatible docking hardware and their different cabin atmospheres.

Successful trial of the new Docking Module could open the way to joint US-USSR space flights of every description. A definite early goal will be equipment for international space rescues, so that our astronauts could come to the aid of Russian cosmonauts in distress, and vice versa.

The newly signed agreement calls specifically, too, for compatible docking systems permitting "joint scientific experiments in the future." Possibilities seen in current speculation range from visits to each other's space stations, up to projects as ambitious as a manned voyage to Mars—sharing what might otherwise be its prohibitive cost.

So, while the Apollo-Soyuz Test Mission is the only joint space flight so far scheduled, hopes run high of what it may lead to.

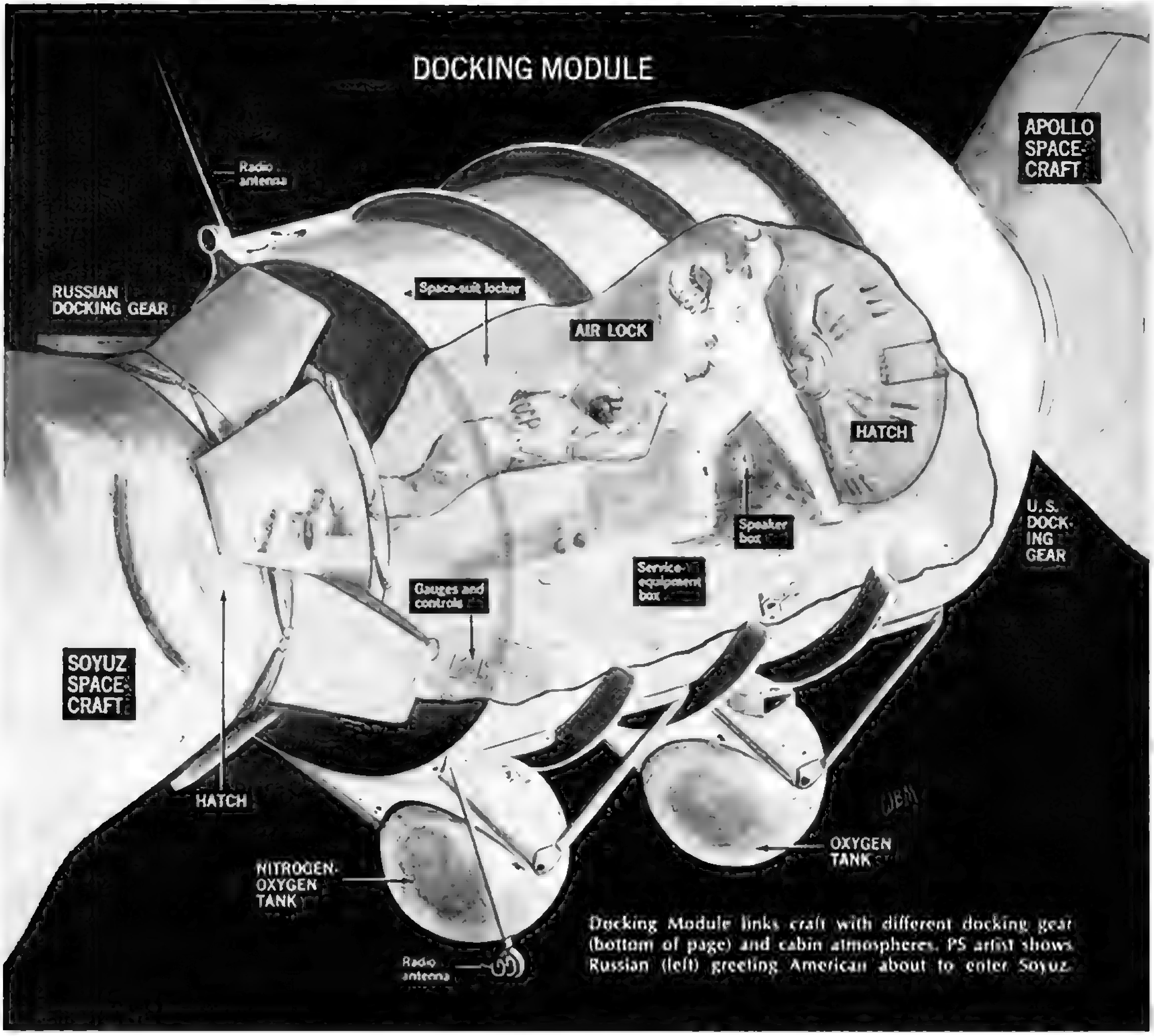
The first US-USSR space flight. Here is the flight plan of the 1975 mission:

A two-stage Saturn IB rocket will boost an Apollo spacecraft, carrying two or three astronauts, into a low Earth orbit about 125 statute miles up. After separation from the second rocket stage, the Command and Service Module will turn around, dock with a Docking Module inside the rocket's nose, and extract it—much as the Lunar Module is extracted in our Apollo lunar missions. The weight of spacecraft and Docking Module will total about 33,000 pounds.

The plane of the orbit, inclined 51.6 degrees to the equator, will take the Apollo over the USSR launch site in Soviet Kazakhstan, about 100 miles northeast of the Aral Sea—the Baikonyr-Tyuratam Cosmodrome.

One to several days later, the Soyuz spacecraft will be launched with two cosmonauts aboard. Its own well-proven launch vehicle will put it into an orbit about 165 statute miles high.

Then the Apollo spacecraft will ac-



Docking Module links craft with different docking gear (bottom of page) and cabin atmospheres. PS artist shows Russian (left) greeting American about to enter Soyuz.

tively maneuver itself into a station-keeping position with the Soyuz, with the help of the Apollo radio and optical guidance systems.

From this position Apollo will proceed to dock with Soyuz, using the new Docking Module—shortly to be described—and a novel TV docking-alignment system.

"Welcome aboard!" An Apollo crewman's visit to the Soyuz is expected to begin a round of calls upon one another. So the historic handshake as Americans and Russians first meet in space may take place inside the Soyuz. Or possibly, as PS's artist visualizes it here, a gracious Russian host might meet the American halfway in the Docking Module to extend a personal "welcome aboard" and

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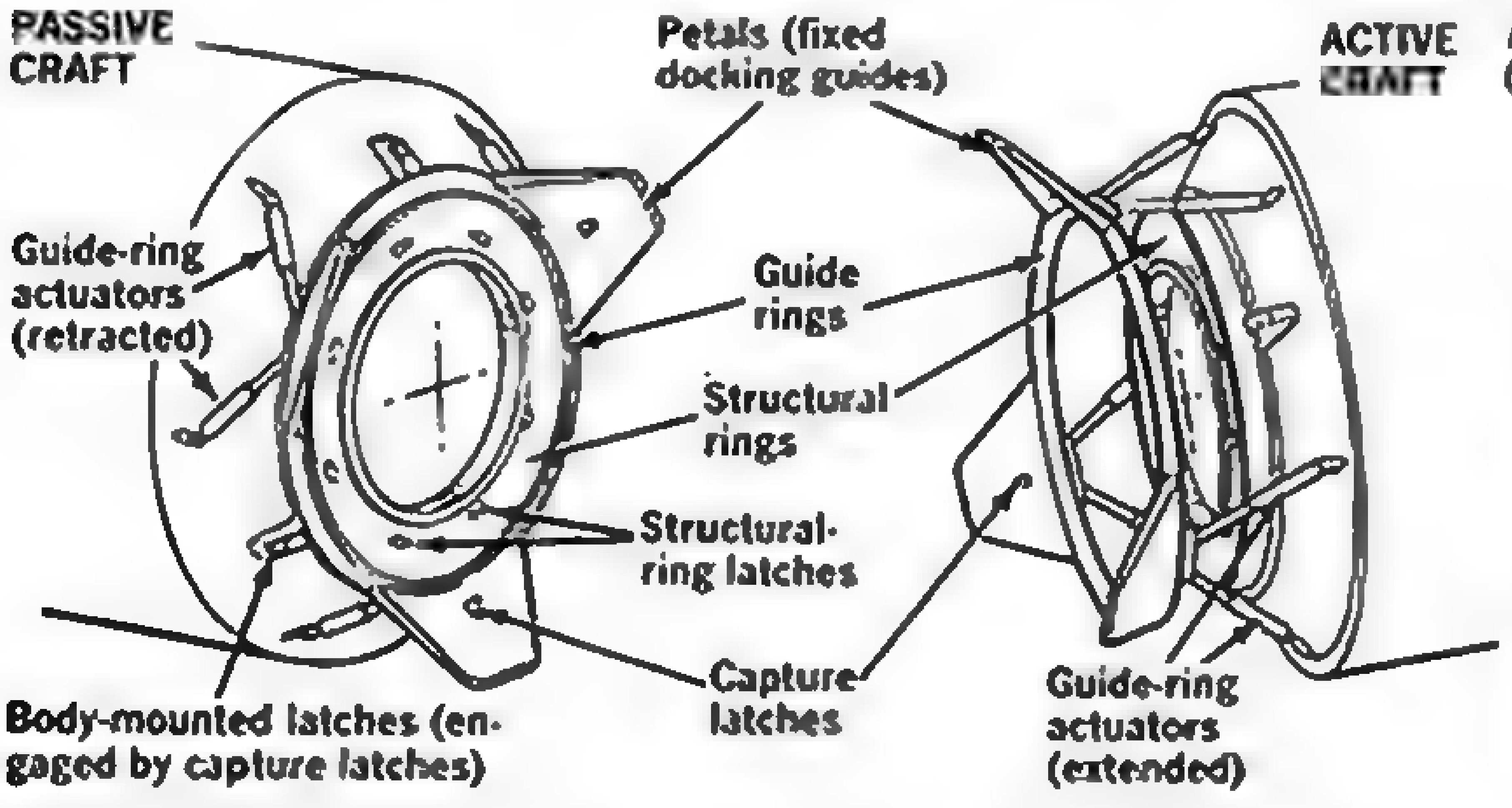
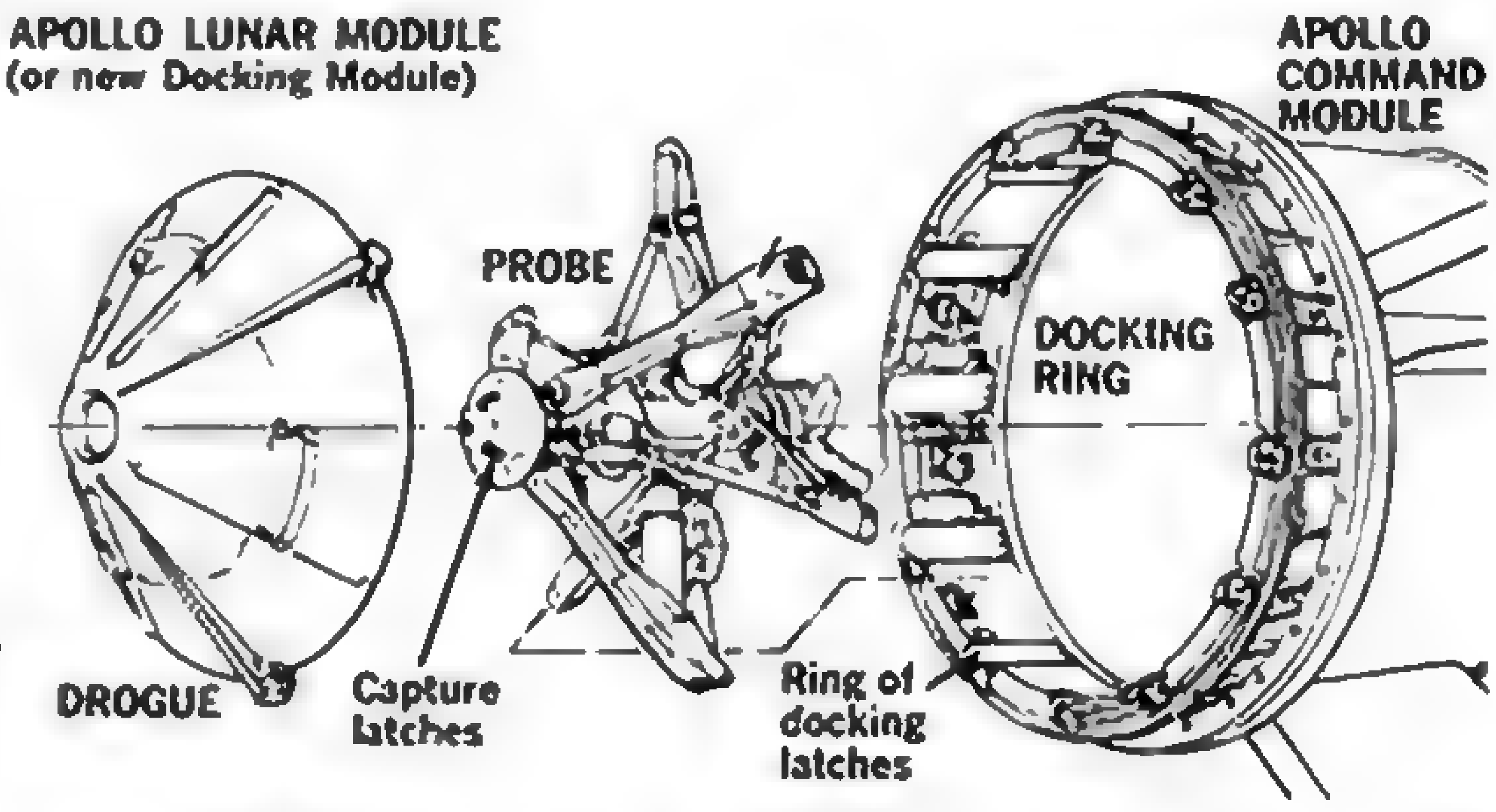
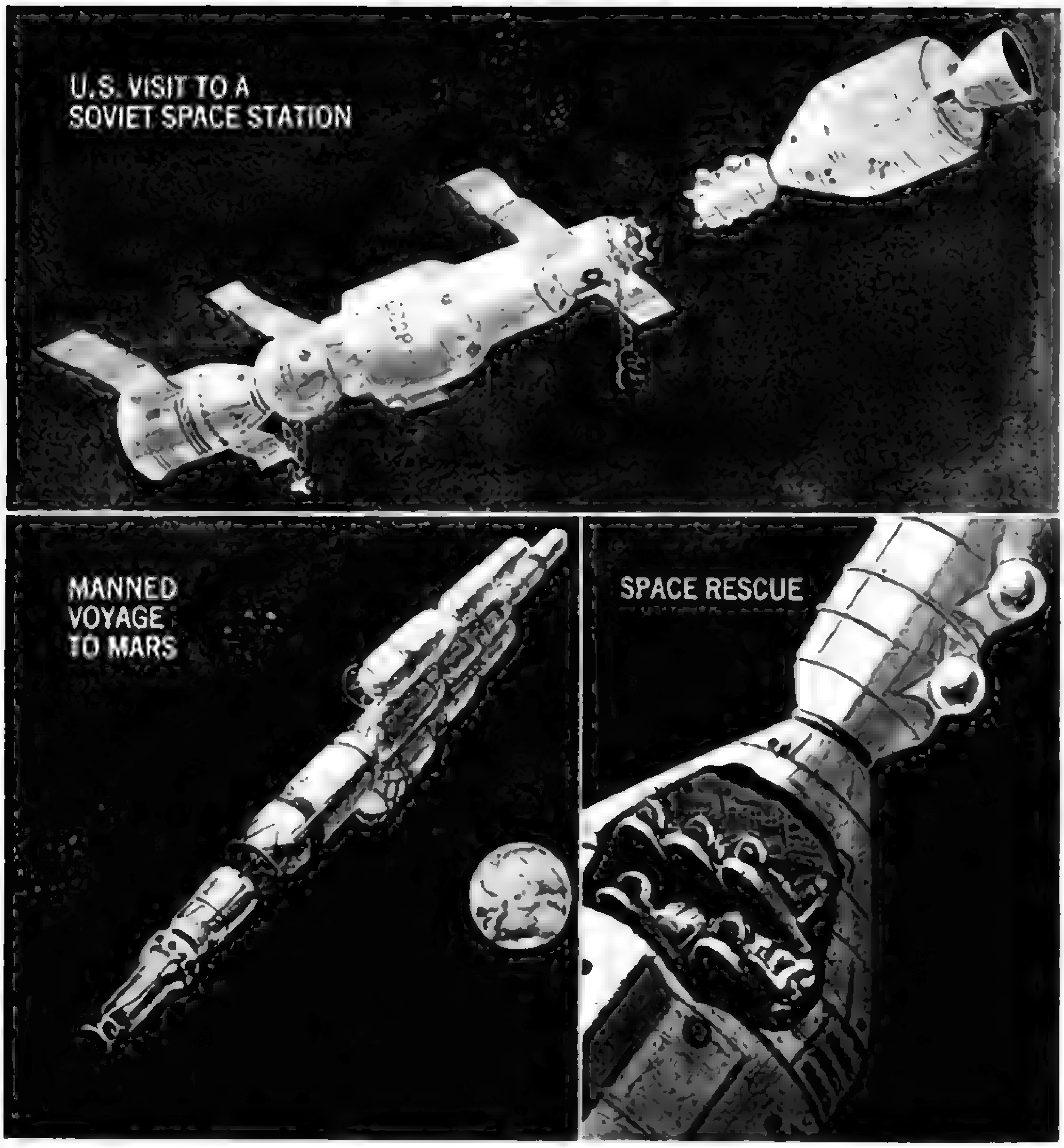


In Russian-favored docking system, latches on petals of one craft engage latches on body of other. Petals' retractable ring draws two craft tight. Structural-ring latches complete docking.



In U.S. docking system, latches on tip of probe engage opening at center of conical drogue. Retractable probe pulls two craft together until ring of automatic latches secures them tightly.



Possible future US-USSR missions, still unscheduled but now seen open to speculation, include these examples. Top, Apollo visits a Salyut space station manned by Russian crew of a Soyuz (already attached). Above left, manned voyage to Mars illustrates costly project that might become feasible jointly. Above right, international space rescues of each country's spacemen by those of other one are called a primary goal of present American-Russian plans. Picture shows what may be nearest thing yet to a suitable vehicle—a U.S. "Skylab crew-rescue command module," to which a standard Apollo Command Module would quickly be converted by a new kit increasing its seating capacity from three to five. (Two men go up, five come back.) Adding a Docking Module as shown would ready it to aid a Soviet craft in distress. In picture here, it could be about to cast off from a stricken spaceship (not shown) with the rescued cosmonauts occupying the extra places inside for the return trip.

escort him back into the Soviet craft.

Next a Russian will accompany the astronaut back to the Apollo.

After two days of visiting and science experiments, the two spacecraft will separate. Soyuz will parachute to a land site in the USSR; and Apollo, to a splashdown in the western Atlantic, for recovery by a naval vessel.

The Docking Module. Both in docking the two spaceships in orbit, and in all movements of crewmen between them, the new Docking Module plays a key role. It is a cylindrical structure, about five feet in diameter and 10 feet long, with room inside for two men in space suits—which would probably be donned only in an emergency.

Its opposite ends will have docking hardware suiting that of the U.S. and Russian spacecraft, respectively. Thus the Docking Module serves mechanically as an adapter, to link the otherwise incompatible docking systems—and enable the existing, flight-proven Apollo and Soyuz spacecraft to dock with each other.

The Docking Module's "American end," like an Apollo Lunar Module, will contain the conical drogue of the standard U.S. probe-and-drogue docking system.

Its "Russian end" will be fitted with the ring-and-petal docking system preferred by the Soviets.

Drawings on the preceding page compare the two types. The Soyuz' system has the attraction of being a "peripheral" one—entirely outside the central hatchway, which it leaves unobstructed. Our own probe-and-drogue system, a center-line one, inconveniently blocks the hatchway and requires hardware to be detached and stowed out of the way, after docking, before a crewman can pass through it to the other spacecraft.

Second major role. No less important is the Docking Module's role as an air lock, to enable crewmen to transfer between spaceships with different cabin atmospheres.

While the astronauts in the Apollo breathe pure oxygen at a pressure of only five pounds to the square inch, the cosmonauts in the Soyuz are used to a luxuriously airlike nitrogen-oxygen mixture at normal 14.7-pound atmospheric pressure. A gradual changeover in the Docking Module's variable atmosphere prepares a crewman of one craft to enter the other.

How long it takes an astronaut from the low-pressure Apollo to adjust to the Soyuz' three-times-higher pressure depends solely on the rate of pressure buildup his eardrums can stand without undue discomfort. NASA estimates that no longer than 25 minutes in the Docking Module should suffice. The problem here resembles that of a *descending* scuba diver.

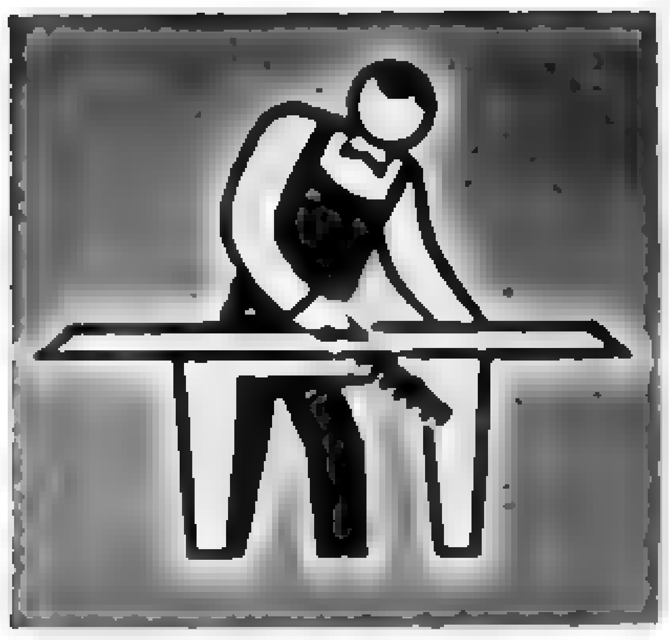
Entering Apollo from Soyuz is another story. This time the problem, like that of an *ascending* diver, is to avert the "bends"—decompression sickness due to release of bubbles of nitrogen previously dissolved in the blood, in going to lower pressure. A stay of approximately two hours in the Docking Module will be required for slow depressurization and equally important prebreathing of pure oxygen.

The entrance-and-exit hatches at each end of the Docking Module will be opened, one at a time, only when its atmosphere's pressure and composition match those of the spacecraft beyond.

Obviously these preliminaries for visiting rule out any scampering back and forth between Apollo and Soyuz. Further limitations are the agreed-upon "ground rules" that an American will be in the Apollo, and a Russian in the Soyuz, at all times; and that two men will be the maximum in the Docking Module at once. Finally, the Docking Module's gas supply (carried externally) sets a limit; it suffices for a total of three round trips by two crewmen.

The story behind the mission. The agreement signed during the Moscow summit meeting gives the final go-ahead for plans under discussion with the Soviets since April 1970, when Dr. Thomas Paine, then Administrator of NASA, informally proposed the desirability of compatible docking units enabling astronauts or cosmonauts to come to each other's help in case of difficulties. This suggestion led to a first meeting at Moscow in October 1970 between members

[*Continued on page 118*]



SHOP TALK

By ROBERT P. STEVENSON

How to adjust your shop tools to suit your height

A reader posed an interesting question some time ago: For a man of average height, he asked, what are the recommended heights for shop equipment to assure both safety and ease of operation? He specifically wanted to know optimum dimensions from floor to tabletop for a workbench, table saw, radial-arm saw, jointer-planer, and drill press; from the floor to the centerline of a woodworking lathe; and from the floor to the working surface of a belt-disk sander.

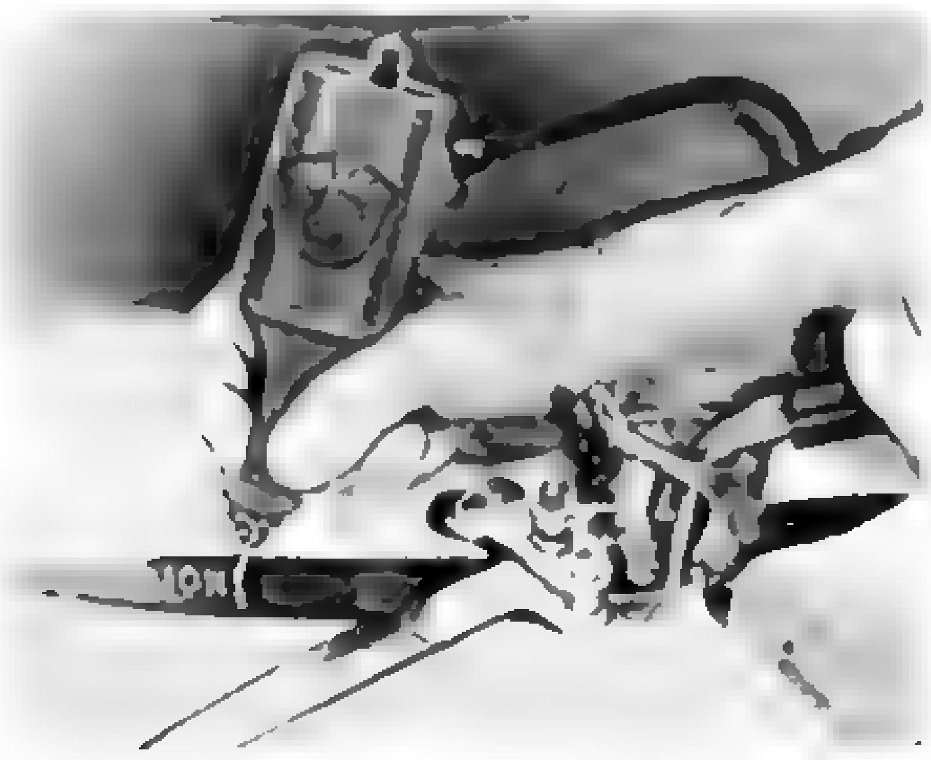
We referred the question to the Power Tool Institute. J. L. Stackhouse Jr., senior design engineer for Emerson Electric Co. (a PTI member), pointed out that ANSI (American National Safety Institute) 01.1-1971 Safety Requirements for Woodworking Machinery state:

For maximum efficiency, it is recommended that the height of the table or point of operation above the floor for various machines be approximately as follows for operators of average (69.3") stature:

Circular saws (hand fed)	36"
Circular saws (power fed)	32"
Band saws	46"
Shapers	36"
Jointers	33"
Lathes	41"
Sanders	36"
Radial-arm saws	39"

These heights are recommended in two recent books devoted to the subject. Tool stands and legs are usually made adjustable to provide variation both up and down from the 69.3" average. The list does not include drill-press table height since this is adjustable by design. Workbench height would be about 36".

Engraving tool helps police recover stolen items



Police departments in more than 100 communities throughout the U.S. have an effective new procedure for recovering stolen articles—or even preventing thefts in the first place. The program is based on one that has been running in Monterey, Calif., since 1963. Under the program, the local police or other sponsoring agency lends an electric engraving tool to families to inscribe their driver's-license number on all items of value in the household. Participating families place "Project Theft-Guard" stickers at their front and back doors, also on bicycles. Costs for developing materials used in the program are underwritten by Dremel Manufacturing Co., Racine, Wis. 53401. Dremel makes electric engravers. These write like a pencil on metal, plastic, wood, and other materials. In San Antonio, Tex., Holy Cross High School has sponsored the program as a means of helping to raise school funds.

New books for the craftsman's shelf

When it comes to framing pictures, you can do a lot of good things with stock molding available at building-supply dealers. A new book shows good examples and gives the required know-how. The book is *Handmade Picture Frames from Simple Moldings* by Ellwood Bauhof and Robert C. Chapin Jr., published by Countryside Press, care of Farm Journal, W. Washington Sq., Philadelphia ($1.95).

A 44-page volume from American Edelstaal, Inc., 1 Atwood Ave., Tenafly, N.J. 07670, is designed both as a general handbook on metal-lathe practices and an operator's manual for this company's compact Unimat. It's priced at $1 for regular-mail delivery.

Other interesting new books I've seen include: *The Art of Making Wooden Toys* by Peter Stevenson (Chilton, $9.95); *Complete Book of Home Repairs and Maintenance* by Jackson Hand (Popular Science, $8.95); *Home Book of Smoke Cooking* by Jack Sleight and Raymond Hull, including how to build several smoke ovens (Stackpole, $7.95).

Joining the Russians in Space

[Continued from page 78]

of NASA and the USSR Academy of Sciences, which resulted in a basic agreement to study compatible rendezvous-and-docking systems for manned spacecraft.

At a second meeting in June 1971 at Houston, it was agreed to study two candidate docking missions: an Apollo to a Salyut space station, and a Soyuz to a Skylab space station.

Apollo and Soyuz chosen. In a third meeting at Moscow in November-December 1971, the technical feasibility of the Apollo-Salyut mission was confirmed, but a number of possibly serious problems of cost and scheduling were seen. The Soyuz-Skylab mission was scratched; Soyuz could not reach Skylab's orbital altitude of 270 statute miles. Further studies led to the decision, in an April 1972 Moscow meeting, to use Apollo and Soyuz. The Soviets selected Soyuz for this mission mainly because of their practical experience with this spacecraft, which has been their primary manned space vehicle since 1967.

Other agreements reached in the series of meetings covered such varied details as hard schedules; who would have what functions of flight control and command; how and where the two crews would be trained to understand each other, and how much familiarity with each other's languages would be needed.

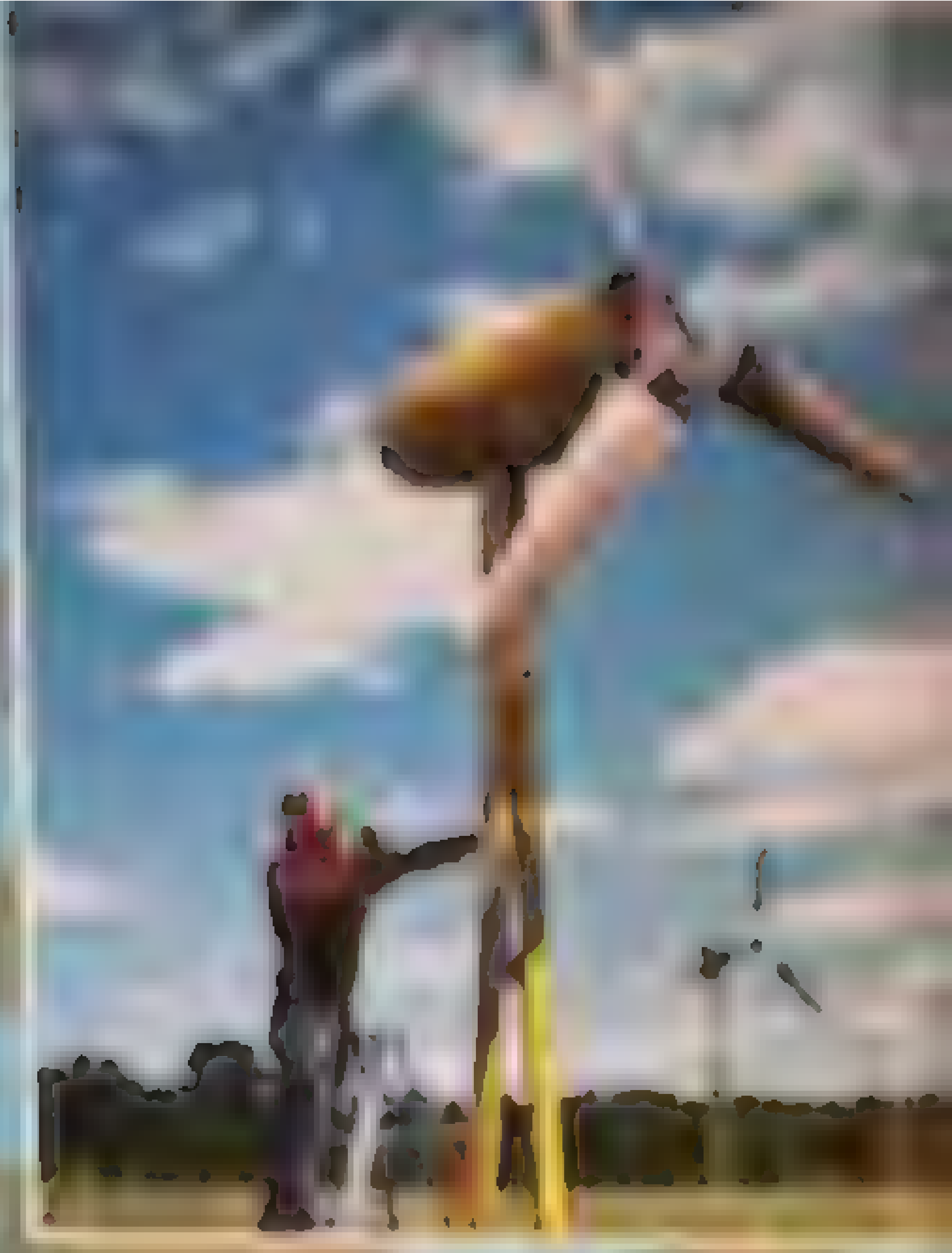
Key figures in these meetings were Dr. George M. Low, Acting (later Deputy) Administrator of NASA, who headed the U.S. delegations, and Prof. M. V. Keldysh, President, Academy of Sciences of the USSR. Dr. G. S. Lunney of NASA and Prof. K. D. Bushuyev of the USSR Academy, who headed two of the Joint Working Groups on technical and operational questions, have been appointed as Apollo-Soyuz Test Project Directors.

Projected schedule. NASA has announced it will begin manufacture of the Docking Module this summer. Building and testing it will take two years—and the 1975 mission date is seen as the earliest when all preparations can be comfortably completed. Soviet engineers will be working side by side with those of NASA, probably in both countries.

Hopefully, the Apollo-Soyuz mission will be only a beginning. The Moscow accord announced that future generations of manned spacecraft of both the U.S. and the Soviet Union will be capable of docking with each other. And many a U.S. astronaut reportedly is boning up on speaking Russian.

Popular Science

THE What's New MAGAZINE



Now They're Getting Serious About Producing Pollution-Free Electric

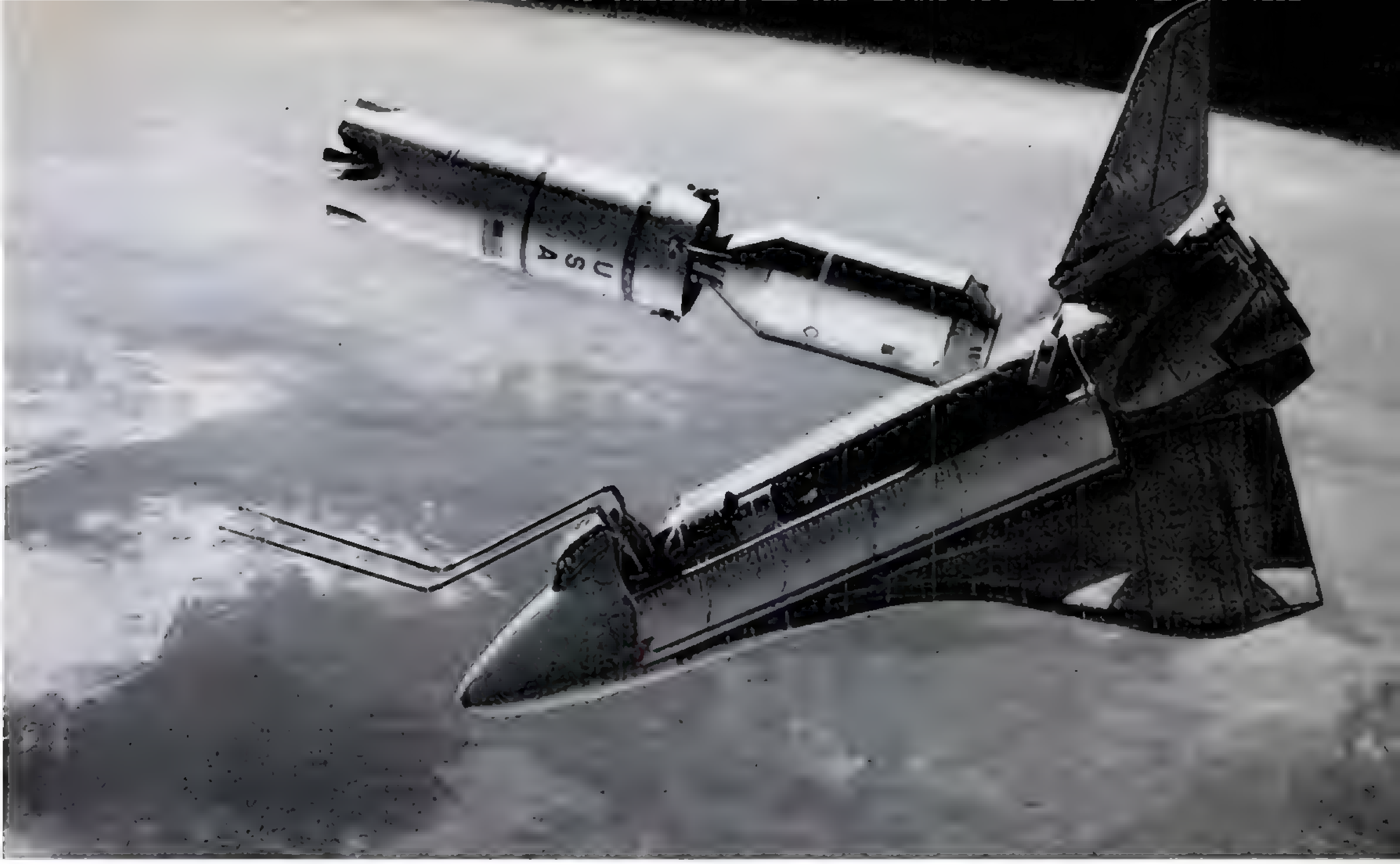
POWER FROM WINDMILLS...

...And Here's an Advanced Design YOU Can Build

STUDDED TIRES
New Facts You Should Know

HOME ELECTRONICS
- How to Fight Interference That Louses Up Your TV Picture
- Buyer's Guide to the '73 TVs
- Those Little Radios That Tune In Something Extra

FRAME-HUNG GEODESIC DOME
Pre-Fab It Now—Put It Up Next Spring



Mechanical arms up to 50 feet long, remotely operated from within, look like "feelers" on nose of Space Shuttle. North American Rockwell artist shows craft launching Space Tug (upper left), pulling satellite it will boost into higher orbit than Shuttle can reach. Schematic drawing below illustrates how orbiting Shuttle will use a radio-controlled Free Flyer, a mini-spacecraft with interchangeable towing gear or manipulators, to retrieve or repair a satellite. Inset of Free Flyer shows it equipped for retrieving.

Spacemen Get Long Reach with Remote-Control Aids

By
WERNHER von BRAUN
PS Consulting Editor, Space

Sophisticated puppets called "teleoperators" can relieve our astronauts of many difficult or dangerous tasks performed in orbit

When one of our coming Space Shuttles repairs a satellite in orbit, or retrieves it for return to Earth, it's likely the job will be done by remote control. Sometimes the actual operator may not even be one of the Shuttle crew, but a man down on the ground.

Little-realized by the public is how extensively the manned Shuttle will rely on *unmanned* devices and ve-

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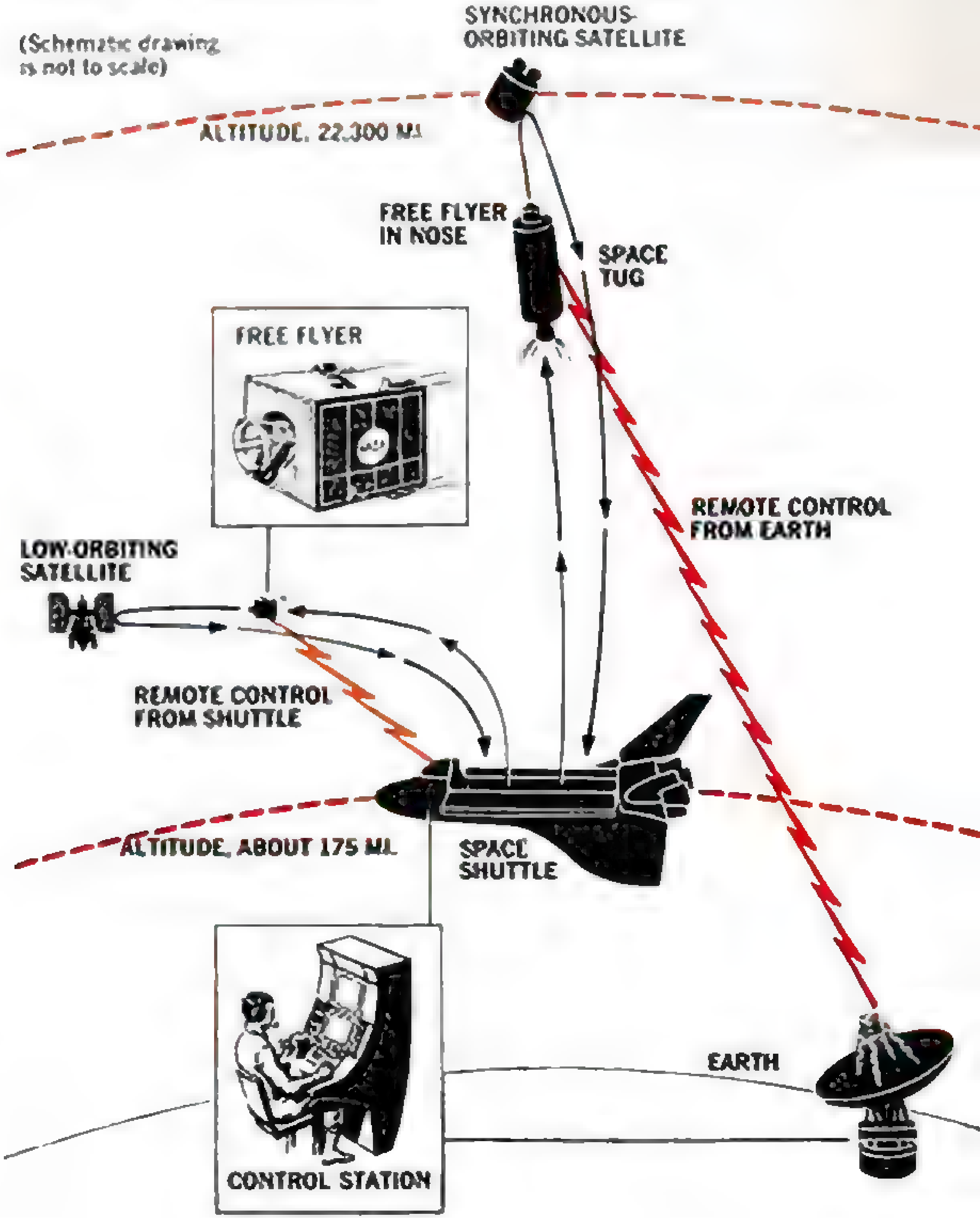


Teleoperators on the moon: Left, scoop on unmanned Surveyor, remotely operated from Earth, tests firmness of lunar soil before Apollo landings. Center, Luna 20 becomes Soviets' second crewless craft to return from round trip to moon with lunar specimens (in one of two cylinders protruding from reentry capsule). Right, NASA scientist happily examines one of specimens obtained by U.S., in swaps, from each Luna haul. Both countries gained by Lunas' feats, since landings were in regions of moon unvisited before.

hicles to perform its orbital tasks. The Shuttle's aids, including a novel crewless mini-spacecraft named the Free Flyer, will be among the most sophisticated of the remote-controlled machines we call "teleoperators"—and will be described here before we are through.

A teleoperator has been defined as "a general-purpose, dexterous, cybernetic machine." "Cybernetic," or capable of intelligently guided actions, distinguishes teleoperators from preprogramed automatons like phonograph record changers, or timer-controlled washing machines. It establishes that man himself is always "in the control loop."

Teleoperators have found favor wherever man wants to perform a difficult task in an environment that is hostile—because of heat, pressure, radioactivity, a vacuum (requiring man to encapsulate himself in a clumsy space suit), or sheer distance, as to other worlds that man can explore only by proxy at the present stage of space-flight technology.

What teleoperators can do. Some oustanding exploits of teleoperators to date offer examples of the key parts they can play in our conquest of space:

Viking lander on Mars in 1976 will seek signs of life, by tests upon soil gathered with sampler on long boom in left foreground.

When our unmanned Surveyor 3 spacecraft soft-landed on the moon in 1967, out went a toy-sized scoop on a lazy-tongs arm, radio-controlled from a pushbutton console on Earth. By digging tiny trenches, it showed the consistency of lunar soil firm enough for astronauts to land and walk upon, before they arrived.

A picturesque Soviet teleoperator, an unmanned eight-wheel roving vehicle called Lunokhod, was soft-landed on the moon in 1970 before our Apollo crews began bringing man-driven cars along. Operated from Earth by a crew of five, Lunokhod roamed the lunar surface for 10½ months with TV eyes [PS, July '71].

Twice the Russians have accomplished the extraordinary feat of gathering moon samples with a core drill on an unmanned soft-lander, and bringing them back to Earth. Luna 16 did it in 1970, and Luna 20 this year.

Not all teleoperators call for remote control over such long range as the quarter-million-mile lunar distance of these examples—or the vast interplanetary distance to Mars, to operate our Viking lander that will seek signs of life on the Martian surface in 1976. Most teleoperators are actually manipulators whose mechanical hands duplicate the motions of an operator's hands, at comparatively close range.

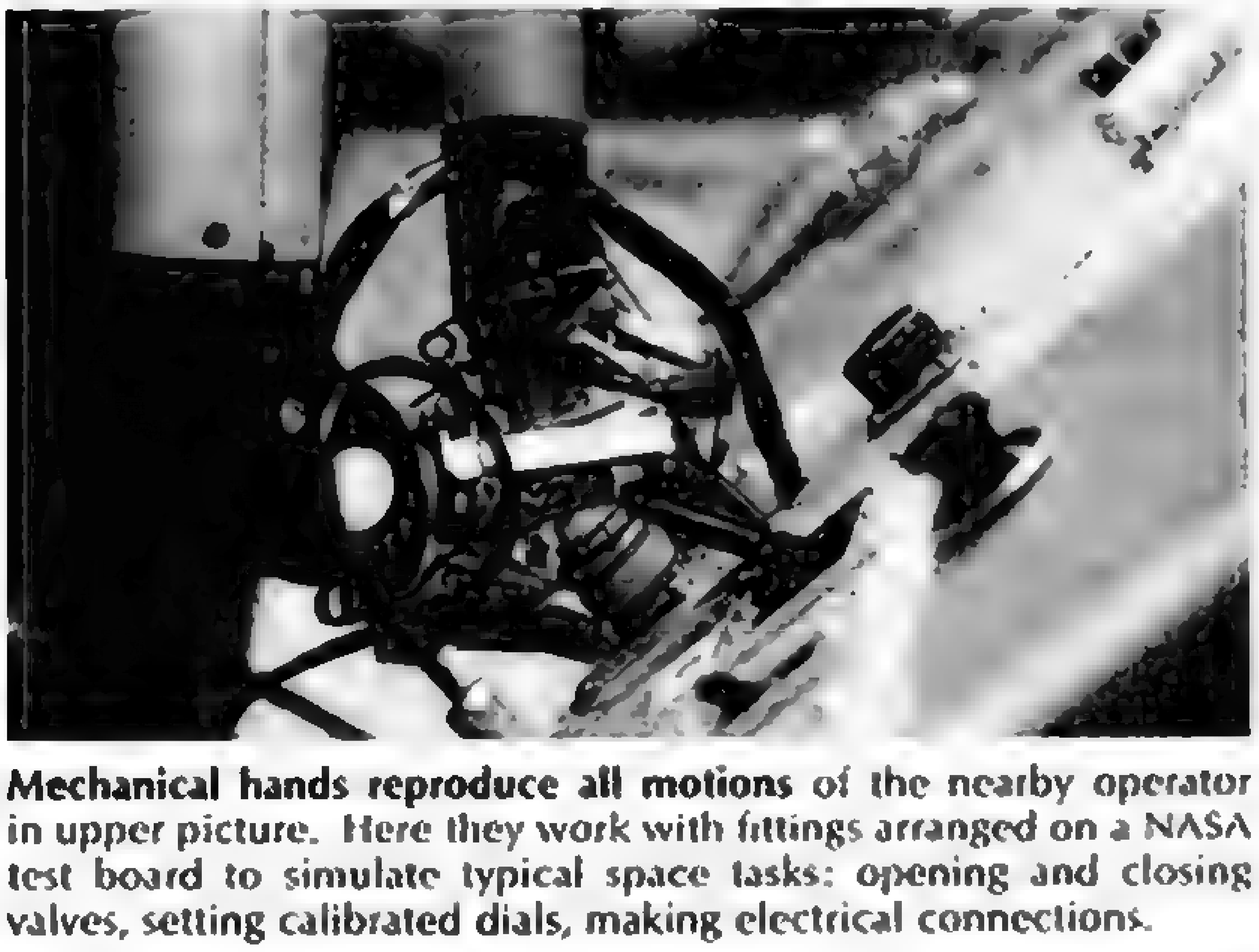
More than 3000 manipulator arms have been built in the U.S. since 1948, most of them to handle radioactive objects safely in atomic laboratories. During a visit to the Oak Ridge National Laboratory, I had an opportunity to marvel at the dexterity of such a cable-operated manipulator system. Working with both hands, I learned within about 10 minutes to open a matchbox placed behind a thick glass window, remove a single wooden match, close the box again, and strike the match! These arms' mechanical control gives a remote sense of touch. Electric or radio control makes such a "force feedback" more complicated, but not impossible to provide.

Beginning in 1961, manipulators to grasp submerged objects have been fitted to submarines and undersea robots. Adapting them for space has followed—and our Space Shuttle will be a showcase of their development.

Remote-controlled gear for the Shuttle. To deploy and retrieve payloads, the Space Shuttle will have an attached manipulator consisting of one to two giant mechanical arms—hinged booms up to 50 feet long, waved like "feelers," and equipped with television viewers. But the Shuttle's remarkable equipment with teleoperators does not end there.

A Free Flyer, expected to be carried aloft in the Shut-

A 1967-model mechanical-arm manipulator at an atomic center, Argonne National Laboratory, is tried out for space use by NASA experimenter in pressurized space suit. To operate manipulator, he inserts his hands in grips on remote-control arms, above.



Mechanical hands reproduce all motions of the nearby operator in upper picture. Here they work with fittings arranged on a NASA test board to simulate typical space tasks: opening and closing valves, setting calibrated dials, making electrical connections.

tle's cavernous 15-by-60-foot cargo bay, will be a mobile teleoperator. Scooting through space under radio control from the Shuttle's cabin, it will dock itself to satellites rendezvoused by the Shuttle, and repair or recover them. As presently pictured, the unmanned box-shaped craft will measure only 48 by 36 by 32 inches and weigh about 400 pounds. Up to 16 hydrazine thrusters will propel it and govern its attitude.

At its business end the Free Flyer will mount any of a variety of interchangeable fittings—manipulator arms, and replacement modules of satellite parts, or a satellite-re-

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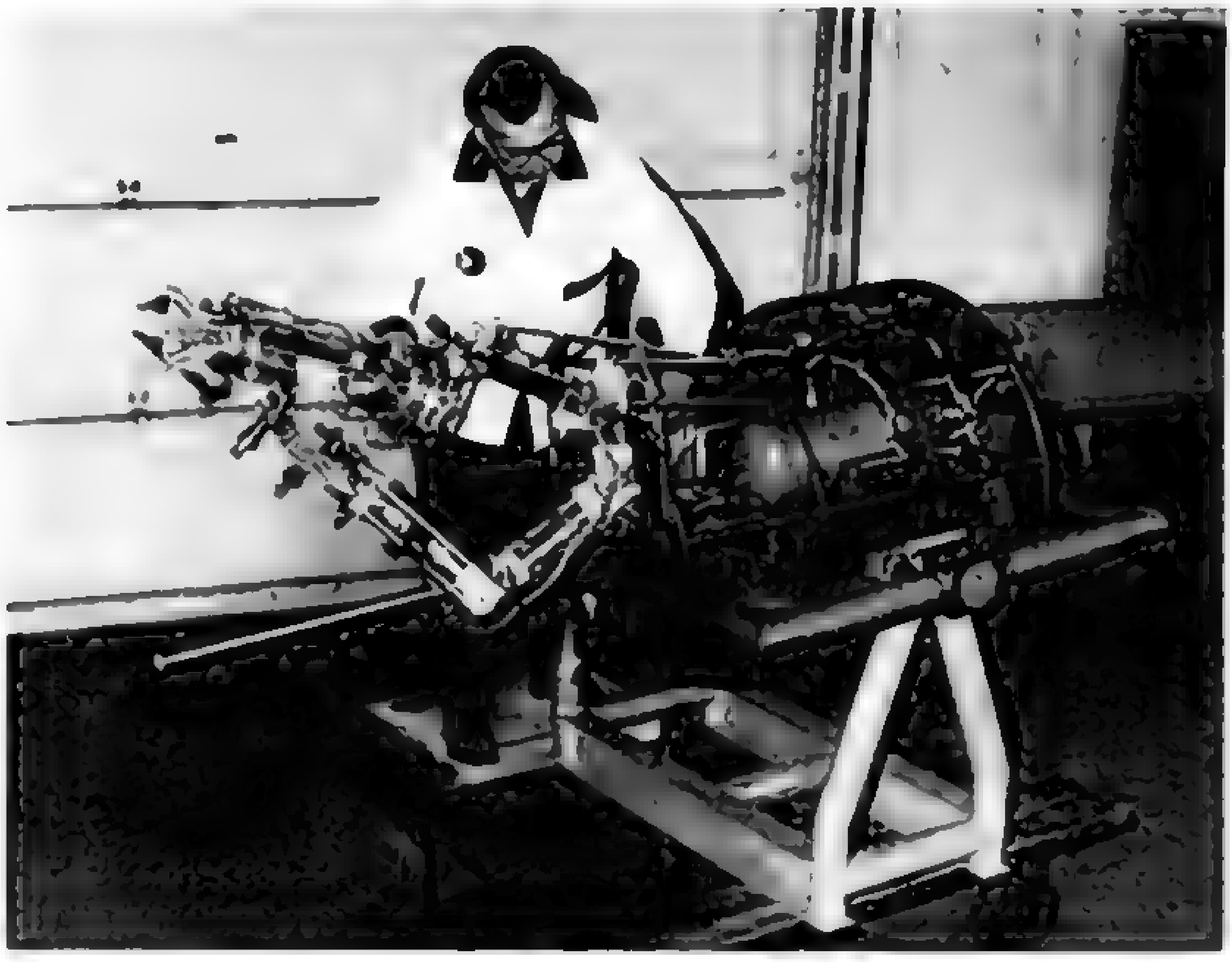
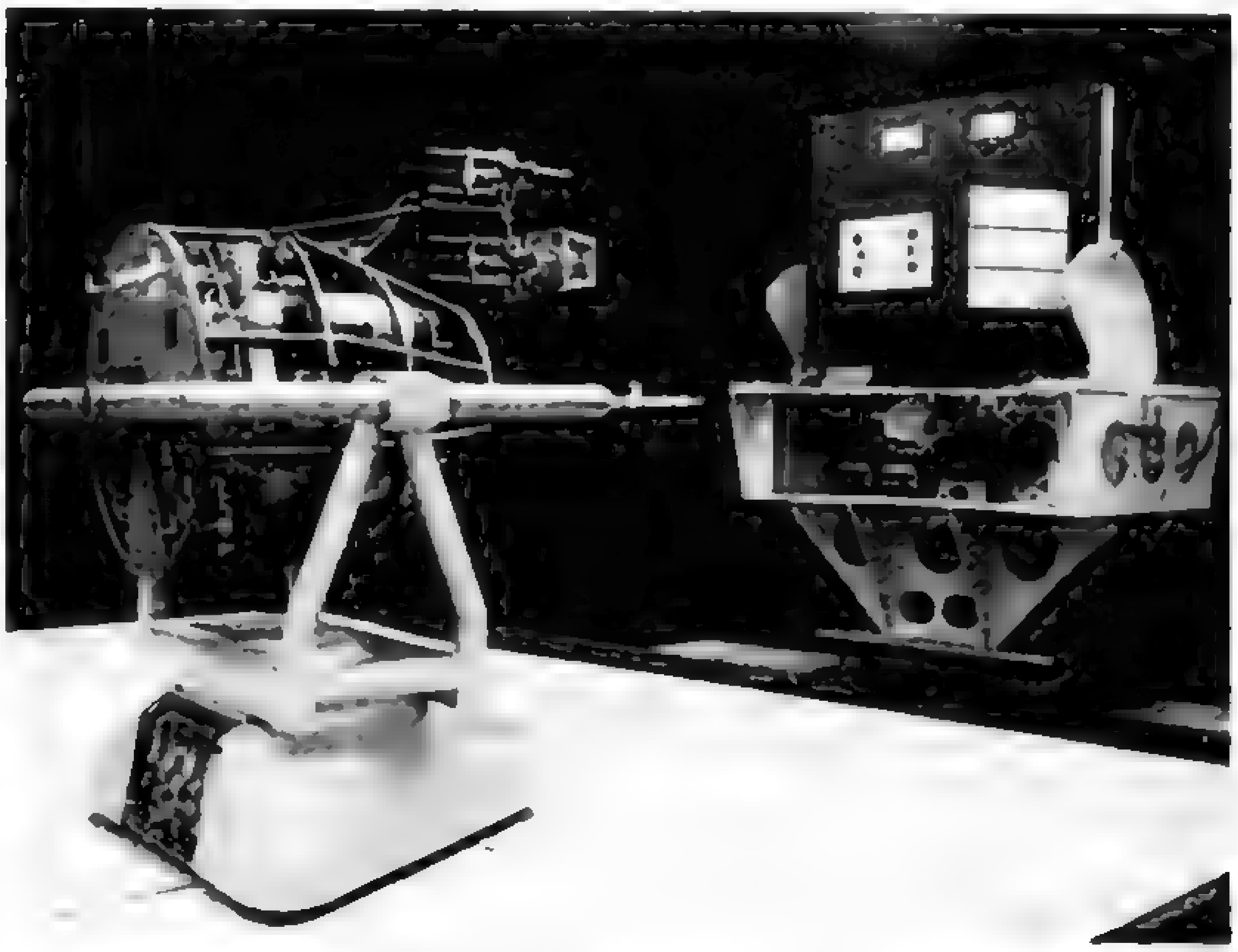
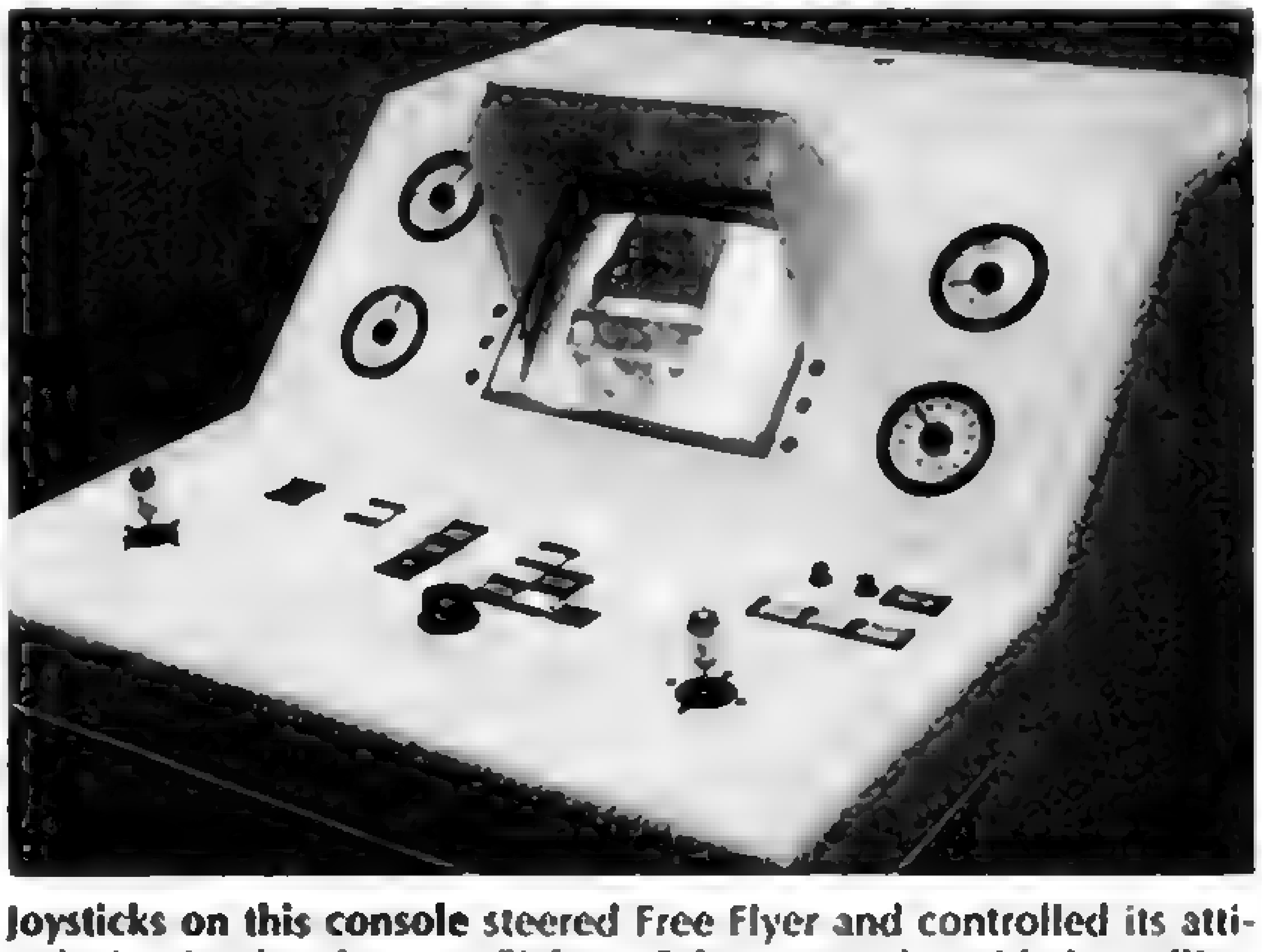
Evolution of mechanical arms has readied them for missions in space



Experimental version of Free Flyer for Space Shuttle is fitted with NASA's latest mechanical arms, for trial "space flights" on a precision-smooth tabletop in 1971-1972, at Buffalo, N.Y. (Photos above and below, from Textron's Bell Aerospace Division.)



Remote-controlled Free Flyer (foreground), propelled by 12 nitrogen jets, glides along table on frictionless air-cushion platform toward "satellite" in background. Interchangeably it carries manipulators, replacement modules, or retrieving gear.



Joysticks on this console steered Free Flyer and controlled its attitude in simulated space flights. Other controls guided satellite-repairing tasks, viewed on TV screen by operator. Trials led to improved two-screen design for control console of future system.

Spacemen Get Long Reach with Remote-Controlled Aids

[Continued from page 75]

:rieving hitch for its "go-fetch-it" role. A TV camera peeping from its top, on the end of an extendable boom, and :wo others at strategic places, provide :lose-up control-console views of oper-ıtions too distant to observe from Shuttle windows. Its flights may be :lose-range ones, of 50 to several hun-lred feet, or may extend to a distance ıs far as several hundred miles.

For missions such as launching a ıynchronous satellite into the re-quired 22,300-mile-high orbit, the Shuttle's orbiting altitude of some 175 miles will fall far short. So its cargo)ay will carry a Space Tug—an un-nanned, orbit-to-orbit rocket vehicle -to take high-flying satellites the rest of the way.

The Free Flyer can ride the nose of he same Space Tug to high orbit, de-ach itself to fix or latch onto a satel-ite, and hitch a ride back down again. During its operations in synchron-ous orbit the Free Flyer will be :ontrolled from Earth, where a syn-:hronous satellite hangs stationary overhead—rather than from the fast-orbiting Shuttle, whose line-of-sight :ontrol path to the Free Flyer would be obstructed by the Earth's bulk every 45 minutes or so.

Trials simulate flights. Pioneer 'space flights" of an experimental Free Flyer took place on a 480-square-'oot tabletop at Buffalo, N.Y., in trials or NASA concluded last February by Textron's Bell Aerospace Division.

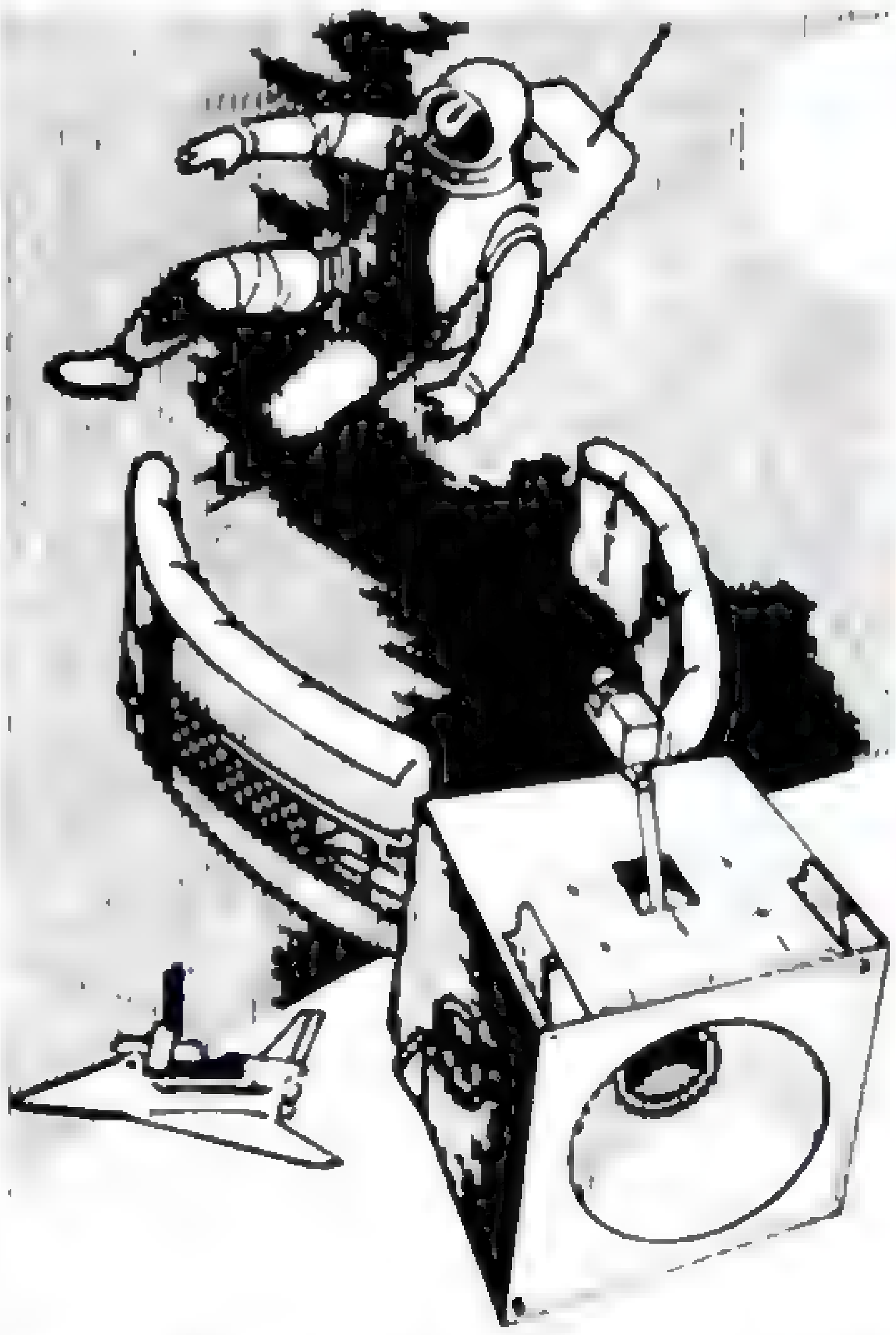
The weird mobile machine rode a hree-cornered air-cushion platform hat could glide without friction ıcross the table's precision-smooth ınd flat surface of plastic-coated ıluminum. Twelve nitrogen-gas thrus-ers propelled it in any direction or rocked it in its gimbal mounting. Its equipment included NASA's latest in mechanical arms, called the Model 12-M General Purpose Anthropomor-phic Manipulator.

Its "pilot" guided it with miniature oysticks on a control console where ı TV screen, linked to a camera on he moving machine, gave him his only view of its maneuverings. A sim-ulated "satellite" at the table's end vas its target.

In a series of trials, the experimen-al Free Flyer succeeded in docking o the satellite, with a simple rodlike probe that latched within a guiding :one. By remote control, it removed ınd replaced a satellite's thruster as-sembly, installed and extended a whip ıntenna, and replaced a battery. It proved a satellite could be refueled in orbit, by connecting and disconnect-ng a coupling for transferring fluids. It detected damaged solar-panel cells, fractured and eroded as if by meteo-roid showers. It opened a port cover, poked a mirror inside, and inspected a valve and electric wiring.

Shuttle repair, caddying, rescue. An August 1972 report to NASA by Bell Aerospace sees many uses for the Free Flyer besides the repertory already cited. Among them:

- The mini-spacecraft could in-spect the Shuttle's heat shield before re-entry—and carry a repair kit to ap-ply a temporary patch of thermal shielding material if needed.
- While a Free Flyer can handle a satellite skillfully—and most safely, if it's tumbling over and over in orbit, studies now indicate—there may still be extravehicular tasks for spacewalk-ers. The Free Flyer could offer them



Rescue of astronaut adrift in space can be carried out with Free Flyer. Scooting to aid, it enfolds him in padded arms and bears him back to Space Shuttle, as visualized in this Bell Aerospace drawing.

"caddy service" to carry cumbersome parts. If an astronaut forgot a tool, or needed a special one, he could send the Free Flyer back for it. An as-tronaut himself could hitch a ride to his work site, and back again, on the little spacecraft.

- Perhaps most dramatically, the Free Flyer could speed to the rescue of a "man overboard," adrift in orbit as pictured above. Well-padded "grappler" arms would gently enfold him and bear him to safety.

And there you have a preview of teleoperators we may see in space by the time, expected to be before 1980, when the Space Shuttle becomes operational. PS

1973

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Popular Science

THE What's New MAGAZINE

Sneak Preview!
All-New Ford MUSTANG FOR '74 Shrinks to 96" Wheelbase, Gets OHC 4 and V6

What the New Domestic COMMUNICATIONS SATELLITES Will Do for You
By WERNHER von BRAUN

Driving OMC's Fabulous New 4-Rotor WANKEL OUTBOARD

ANNOUNCING PS WEEKEND-PROJECT COMPETITION
Your Idea May Be Worth $Money!

New KROV Steam Engine: Key to Power from Solar and Geothermal Energy?

More Speed, Less Effort—Research Shows How to
TUNE YOUR 1[illegible]D BIKE

What the New Domestic COMMUNICATIONS

By WERNHER von BRAUN
PS Consulting Editor, Space

On Jan. 11, 1973, Rudy Pudluk, community manager of Resolute on a Canadian island above the Arctic Circle, made a long-distance phone call to Ottawa. The English-speaking Eskimo chatted with Gerard Pelletier, Minister of Communications, and with David Golden, president of Telesat Canada, whose system carried his voice across the frozen North.

His call began commercial operations of Anik 1, North America's first domestic communications satellite—and the world's first domestic one in a synchronous orbit, like that of our transocean Intelsat satellites.

Canada's Anik satellite for domestic communications, above, has set the style for U.S. versions due next year. Antenna at top is of fine "see-through" mesh.

Anik 1 was launched from Cape Kennedy on Nov. 9, 1972. It hangs stationary with respect to Earth, 22,300 miles high, over the equator and the eastern Pacific at 109° west longitude (which puts it due south of Gallup, N.M., and midwestern Canada). From its lofty height it views Canada coast to coast.

By the time you read this it will have been joined nearby in orbit by an identical twin, Anik 2, if all has gone well. One communications satellite has ample relaying range to span the continent; Anik 2 will simply add more message-carrying capacity, and be a backup in orbit. Anik 3, completing the litter, will be kept on the ground as a spare.

Within a year the United States will follow Canada's example and launch domestic communications satellites of its own. They'll transmit phone calls, television programs, telegrams, Telex, U.S. Postal Service Mailgrams, facsimiles of documents, computer data. A hotel-reservation service may find you accommodations via satellite.

A new kind of message net. For years we've enjoyed the advantages of transocean phone-and-TV satellites—but the Western world has waited until now for domestic ones, satellites linking points within a country's own borders.

Understandably they came first in the Soviet Union—a nation with interior distances so vast that people in Vladivostok are awakening to a new day, when their countrymen in Kiev are going to bed the night before. Since 1965, the USSR has been spanned by Molniya ("lightning") domestic communications satellites in elliptical orbits at steep angles to the equator.

Communications have to be switched from one Molniya to another as they pass successively over the country. Currently, however, the Russians are reported to have developed a synchronous version (awaiting launching at this writing) that will stay put in the sky as the Aniks do.

Anik means "brother" in Eskimo—and Telesat Canada, established by the Canadian Parliament in 1969, has set up a network extending all the way from Canada's densely populated south to the remote northern settlements of its Eskimos and Indians.

The 37 satellite-linked earth stations of its initial net include two "heavy-route" ones at the Toronto and Victoria transcontinental-route terminals, with 98-foot dish antennas resembling those for global satellites; other stations' dishes are smaller. Six "network television" stations transmit and receive TV; 25 "remote TV" stations receive it only.

"Northern telecommunication" stations at Resolute and Frobisher Bay establish a moderate-traffic phone link to lines in the south. "Thin-route" stations on Baffin Island and at Igloolik provide limited phone service to small Arctic communities. High-frequency radiotelephone links, available only two hours a day and subject to interference and fading, served Arctic outposts before.

What Aniks are like. Skillful design makes Anik an "economy" satellite. At bargain cost it offers phone-and-TV capacity in the same class with the big Intelsat IVs from the same maker, Hughes Aircraft.

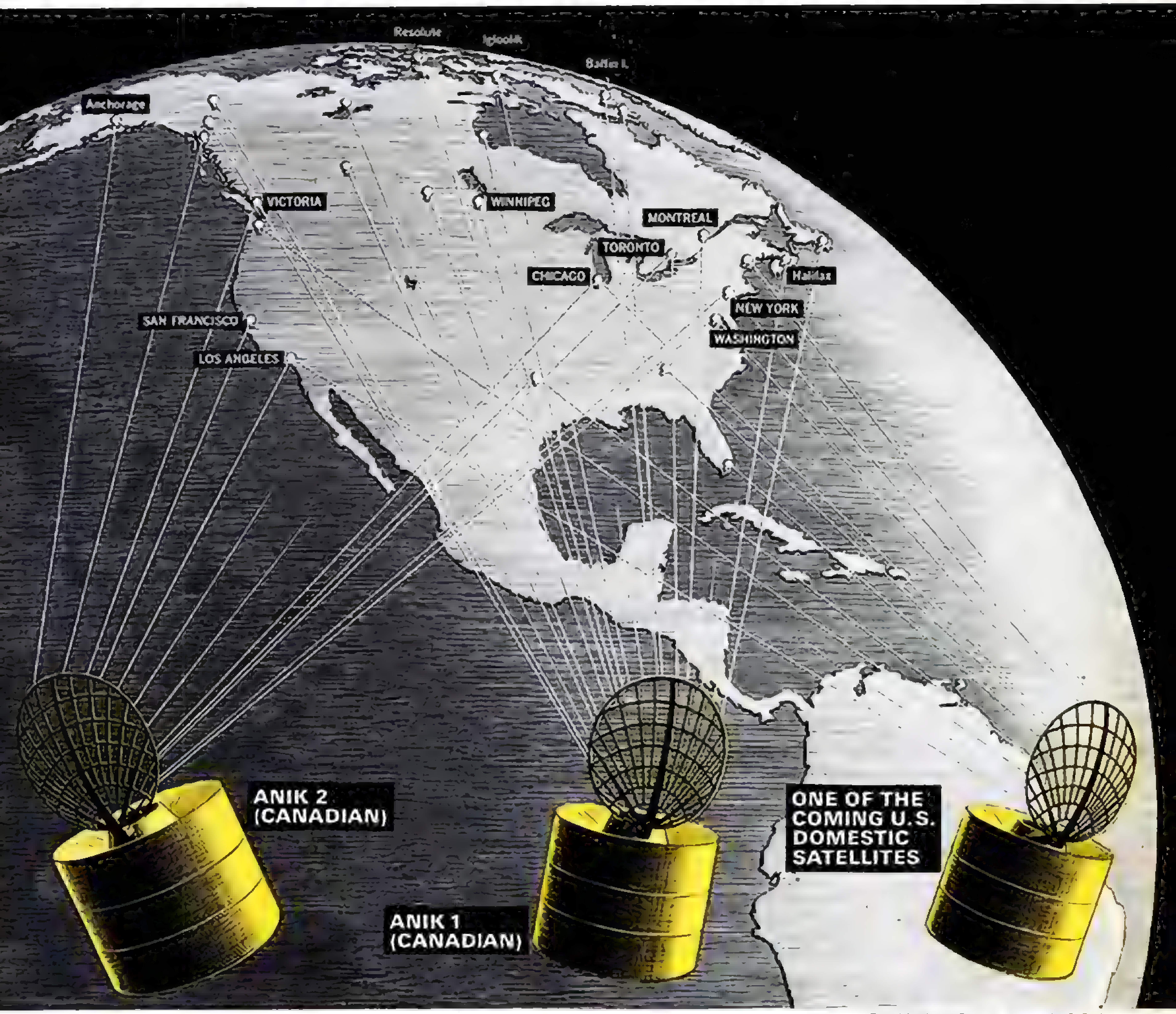
Smaller than an Intelsat IV (11½ feet high instead of 17½) and much lighter in weight (about 1200 pounds at liftoff, vs. 3100), an Anik is less expensive to buy, and to launch into orbit, a service for which the owner reimburses NASA. A Thor-Delta vehicle suffices, rather than the huskier Atlas-Centaur it takes to loft the Intelsat. All told, an Anik in orbit costs about \$16½ million, compared to about \$29½ million for an orbited Intelsat IV. It likewise is designed for a seven-year lifetime.

Chunky little Anik receives signals from Earth, and retransmits them back to other points, with a five-foot parabolic antenna of fine gold mesh rather than a solid dish. For electric power, some 20,000 solar cells surround Anik's drum-shaped body. According to Telesat Canada, an Anik satellite's 12 transponders (radio repeaters) give it a total capacity of up to nearly 12,000 one-way voice circuits—enough for 6000 two-way phone conversations—or 12

Continued

Canada's pioneering Aniks, and U.S. successors, are introducing the revolutionary innovation of overland telephone-and-TV relays in the sky. They promise bargain rates for long-distance phone calls, picture phones that everyone can afford—and better television programs, by way of novel kinds of TV networks

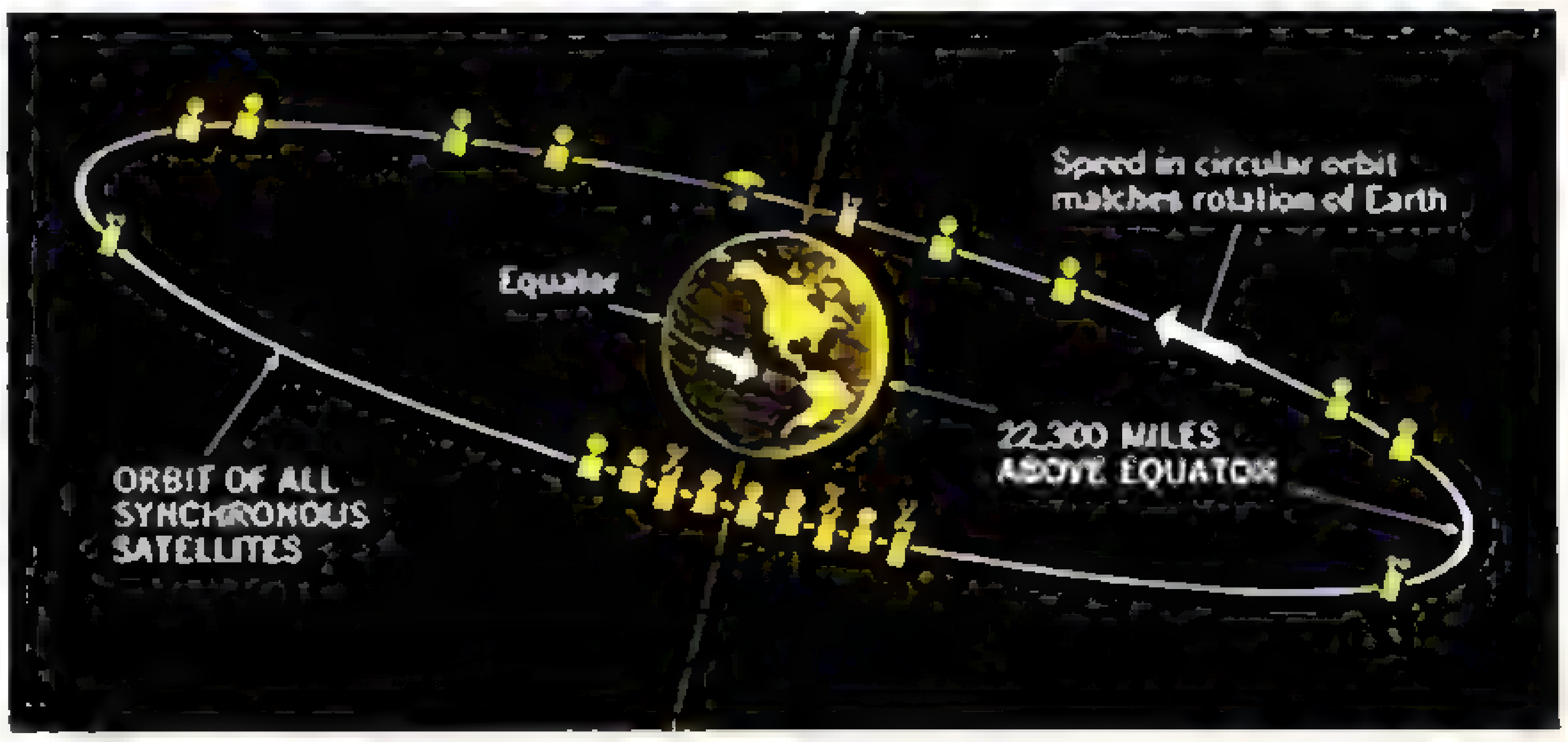
SATELLITES Will Do for You



DRAWINGS BY RAY PIOCH

Three domestic phone-and-TV satellites in action

Anik 1 interconnects Canadian points. Anik 2's spare channels will enable U.S. users to link U.S. cities, plus some Canadian ones, until U.S. domestic satellites (one shown) come along. Drawing shows some of Canada's initial 37 Earth stations, and locations proposed for first ones here. Contrary to what a layman might suppose, Aniks do not fly over Canada, nor will ours over U.S. All circle Earth 22,300 miles above equator—only possible orbit (smaller drawing) where they can match speed and direction of Earth's rotation, and so hang stationary or "synchronous" with respect to Earth, to act like microwave towers 22,300 miles high.



Canada's example spurs plans for early U.S.

Ground stations of new domestic satellite nets use dish antennas ranging downward in size from this typically big one of global Intelsat satellite system.

Intelsat IV global-system satellite (here concentrating "spot beams" on selected Earth areas) has rival for message capacity in economical new Anik satellite.

color television programs, at once.

Up to within a few months of Anik 1's launching, the United States had done little about domestic communications satellites of its own.

It had been a pioneer with communications satellites. It played a leading part in establishing the Comsat/Intelsat net of global satellite links; and the Aniks themselves were built by a U.S. firm. But U.S. domestic ones long went neglected, for a simple reason: The U.S. already had a splendid network of coaxial cables and microwave towers, which seemed entirely capable of providing good long-distance communications and of expanding fast enough to meet ever-growing needs.

Domestic communications satellites, however, can do things far beyond the reach of any earthbound system. Realizing this, the Federal Communications Commission cleared the way for them on June 16, 1972. It laid down the basic rules in a memorable "open skies" decision, which assured lively competition in the field:

A go-ahead for U.S. systems. The FCC announced it was ready to license a limited number of technically and financially qualified U.S. companies to set up their own commercial systems of domestic communications satellites. Each system was to consist of the necessary space elements and ground stations, and would be expected to offer its channels to an emerging market of interested customers.

The scramble was on!

Some U.S. companies couldn't wait to get their own satellites into orbit, and began setting up arrangements with Telesat Canada to lease Anik channels—which could serve U.S. cities just as well. Canadian users' needs already claimed most of Anik 1's capacity, but Anik 2 would have plenty to spare. The American Satellite Corp. and RCA were among prospective U.S. Anik customers.

Efforts to get systems of U.S. domestic communications satellites into early operation looked much like a race, with at least seven contenders. These were examples:

Even before Hughes had completed Canada's three Aniks, it had Western Union's order for three more of the same. Western Union planned to orbit the first of them before mid-1974. Its "Westar" domestic-satellite system, besides carrying its own messages, would have channels to lease to all comers.

American Satellite Corp. (jointly owned by Fairchild Industries and Western Union International) contracted with Hughes for three 12-transponder domestic satellites, and made a down payment to NASA for a first launch in the third quarter of 1974. By then it planned to have a network of eight ground stations, near New York, Dallas, Chicago, Washington, Atlanta or Miami, Los Angeles, San Francisco, and Seattle.

It has also initiated, with Fairchild, design and development of an advanced 24-transponder domestic communications satellite for future use in its system.

Big ones by 1975. For lease to AT&T, Communications Satellite Corp. will establish a U.S. domestic-satellite system with four big satellites, three in orbit and one on the ground. The first is to be launched in 1975. Announced details show them to be as large as Comsat's global Intelsat IVs and of even greater message capacity:

They'll be about 18 feet high and weigh about 3100 pounds at liftoff by Atlas-Centaur vehicles. Each 24-transponder satellite will provide some 14,400 two-way voice-grade circuits. It will have two dish antennas of five-foot diameter, one vertically polarized and the other horizontally polarized (see box on technology below).

The three orbiting satellites will provide domestic-satellite service to all 50 states and Puerto Rico, and will be incorporated into AT&T's nationwide network "to expand and diversify its services to customers."

A satellite in synchronous orbit (as all these coming ones will be) is like a 22,300-mile-high microwave tower. It is in line-of-sight contact with every point in the U.S. Radio energy can therefore be beamed up to it ("uplink") and down from it ("downlink") in straight lines. Relatively short stretches of land lines, of course, connect users with the nearest Earth terminals.

Innovations we'll see. Changes we can expect domestic satellites to bring about have been compared to those from paperback books. Books weren't new; the real novelty of the paperbacks was their availability in so many places and at such low cost.

Even the most conservative plan-

What's ahead in domestic satellites' technology

Reducing ground stations' cost will help them grow in number to make the most of domestic communications satellites. This can be done by boosting power (and cost) of the satellite. The trend is that way in the Intelsat community—so a trans-ocean message to a developing country's $3-million ground station won't incongruously have to reach a town 50 miles away by the local tom-tom system. (It had been only logical to put the burden of weight and expense on the ground when the satellites and launch techniques were in their infancy.)

As important as higher power is "spectrum conservation." Frequencies are limited; separate use of the same frequency in "vertical" and "horizontal" polarization makes them go twice as far. The electromagnetic waves swing up-and-down, left-and-right, respectively. Careful antenna and circuit design can keep them from interfering with each other. An alternative is to aim two beams of identical frequency at different spots on Earth—as can be done with large enough antenna dishes, far enough apart.

domestic satellites

ners expect the FCC's "open skies" ruling to revolutionize the entire pattern of telecommunications in the United States. Here is why domestic communications satellites ("domsats" as they're already being called for short) are so exciting:

- They can provide many more channels, for the same investment, than conventional long-distance cables or microwave lines.
- A domestic communications satellite can carry a telephone call from Washington to Los Angeles as cheaply as from Washington to Baltimore.

Beyond a certain distance—say, 1000 miles for the present—the satellite route is the more economical one. First rates proposed for leasing U.S. domestic-satellite voice circuits give a striking example. The cost is only one-third as much as for coast-to-coast voice-grade circuits by land routes.

Presuming that the ultimate user will eventually share the benefit of the saving, agreeably lower rates for long-distance telephone calls could be your introduction to the practical advantages of domestic satellites.

- Communications satellites can connect one point with a multitude of other points—unlike a coaxial cable or a string of microwave towers on the ground, which always go from one point to another point.

In a TV hookup, for example, a domestic satellite can relay a program originating in New York to 50 or more TV stations throughout the nation, for local transmission—either via broadcast or cable TV.

Better TV on the way. Joining cable-TV systems into regional and national networks by satellite may be foreshadowed as early as this month. Subject to FCC clearance, an East Coast program was to be transmitted to Anaheim, Calif., by way of Anik in a June trial planned by TelePrompTer Corp., the largest cable-TV operator. This would test the feasibility of its "spacecast" plan to connect its cable-TV systems in 33 states and two Canadian provinces with a U.S. domestic satellite in 1974.

The predictable hook-up of local cable TV to satellites will drastically change our entire mode of distributing television programs.

A vast number of available uplink channels can simultaneously bring an advanced satellite dozens of different programs, originating in different cities. Each receiving station can draw upon a rich variety of fare for its viewers' delectation. Moreover, the number of receiving stations can far exceed the present number of television stations, because they quietly feed the received signal into the local TV cable, rather than tying up a precious frequency "on the air."

You'll have a wider choice of what you want to watch through a recent FCC ruling: Franchises for new cable-TV installations, henceforth, will be granted only if they provide two-way communication.

If you prefer a free program sponsored by a commercial advertiser, fine. If you don't want to miss a particular noncommercial pay-TV program—one of 50 programs the satellite may offer at the time—you just punch a two-digit number into a "touch-tone" communicator on your television set. The cable relay station will release the requested program to your set, and bill you at the end of the month.

In this way TV at last will break free of "lowest common denominator" programs (which often capture the highest Nielsen ratings), and be able to meet the infinite diversity of individual tastes.

TV will also be enabled to make a much greater contribution in the field of education. Congestion at campuses could be relieved if students went to their universities only for seminars, discussions, and laboratory work, while boning up on their chosen subjects via TV.

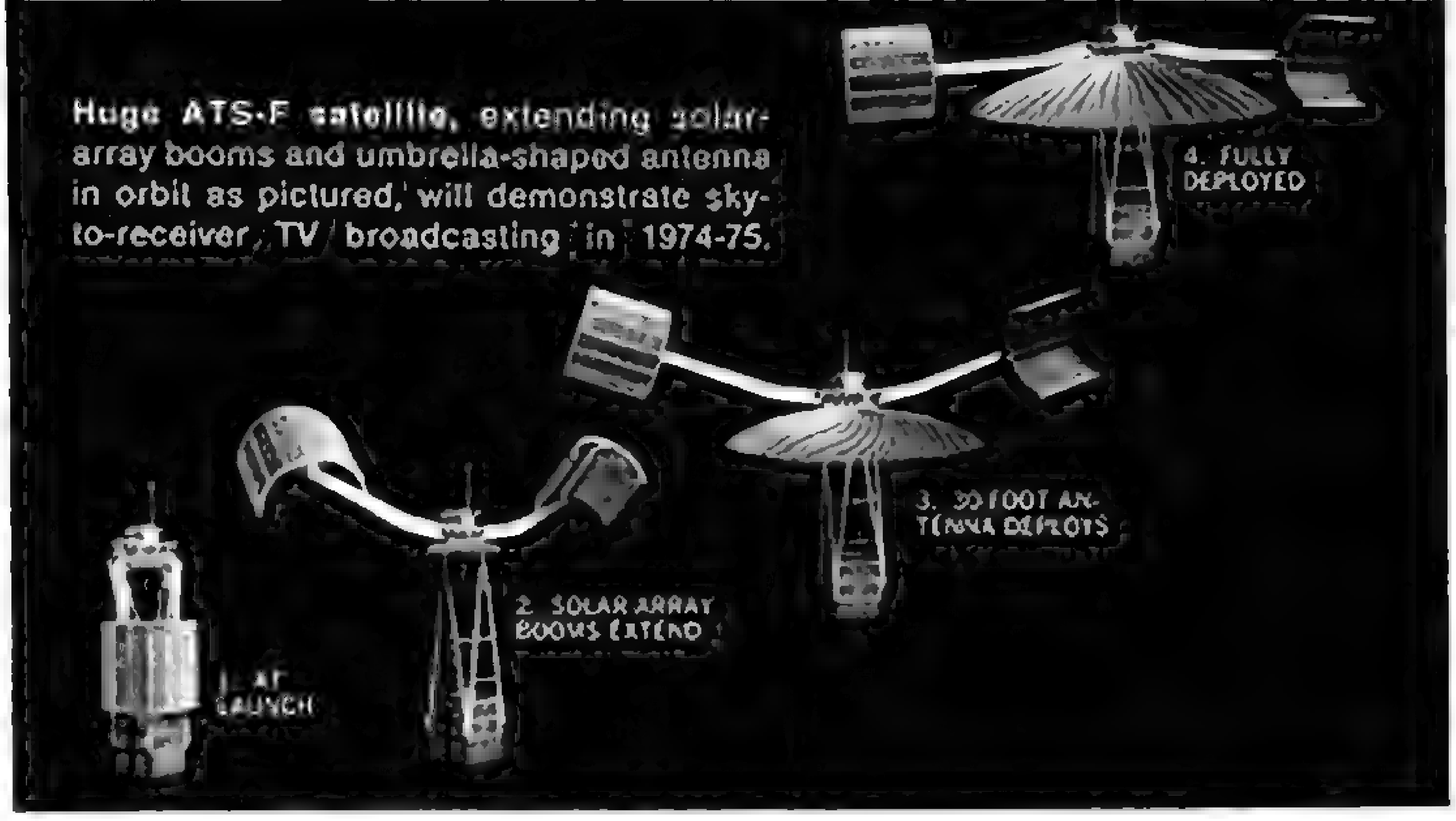
TV direct from the sky. A high-powered synchronous satellite can broadcast TV programs, beamed up to it from a central ground transmitter, direct to specially equipped individual receiving sets on Earth. (Due to the shorter frequencies used, the familiar rake-shaped TV antenna will be replaced by a wire-mesh dish about the size of a beach umbrella.) While this may be a long way off for home entertainment, it has immediate interest for educational programs in remote areas.

As soon as next year, the huge Fairchild-built ATS-F television-broadcast satellite, first of its kind, will give the idea a trial. (ATS is for Applications Technology Satellite, a many-purpose NASA series; F designates the sixth.)

Weighing 2800 pounds at launch by a Titan III-C into synchronous orbit, ATS-F will unfold in space great solar-panel booms of total 52-foot span and an umbrella-shaped antenna of 30-foot diameter. First, in U.S. experiments, it will broadcast educational programs to Indian reservations in the Rockies, and to Eskimo settlements in Alaska.

In 1975, ATS-F's thrusters will nudge it around the equator from the Pacific to the Indian Ocean for a momentous trial of a plan to beam educational TV all over northern In-

[*Continued on page 144*]



Huge ATS-F satellite, extending solar-array booms and umbrella-shaped antenna in orbit as pictured, will demonstrate sky-to-receiver TV broadcasting in 1974-75.

Higher frequencies will reduce the size of large, cumbersome-to-launch antenna arrays and ultimately permit steerable needle-sharp beams to be pointed down at small-area ground targets. That will open the way to high-speed channel switching, another way to get more mileage from limited frequencies. When the satellite relays a TV program to a ground station or a number of them, of course it ties up that frequency for the program's duration. But the frequency used to relay a rare telephone call to a remote town can be reassigned to another call in much less time.

Beam-steering and frequency-reassignment require sophisticated equipment. To route a dial-phone call, you dial digits that activate a string of switching relays. A similar coded instruction will be sent to future satellites from the call-originating ground station. Solid-state switching equipment will select an available downlink frequency and aim it by needle-sharp beam at the destination. A great number of beams can emanate simultaneously from a satellite.

Advanced technology will enable one satellite to handle 100,000 circuits or more with ease.

Communications Satellites

[Continued from page 71]

dia [PS, May '70]. Experimental broadcasts will go to community TV receivers set up for the purpose in hundreds of remote villages.

Success of this ATS-F experiment would open the way to a projected operational system of India's own, which could well make it the first country with direct sky-to-receiver television on a national scale. The full-fledged system would reach as many as thousands of villages via satellite, with educational programs broadcast in local tongues and suited especially to local needs.

More things are ahead. Steerable needle beams (see "technology" box) will open up a new era in communication with moving vehicles. Telephone service enroute can be provided quite readily for passengers in aircraft, ships, buses, and autos. In the eighties, automobiles will come with a circular receive-and-transmit antenna buried in the roof, flush and invisible. It will permit you to call anyone else on the globe from your moving car.

Picture phones for everyone. The almost unlimited channel capacity of communications satellites will finally transform video telephone service from an expensive luxury into a popular-priced amenity of everyday living.

This will not only be good news for young lovers—it will also help to keep fathers and husbands at home. Future monthly meetings of a national corporation's general managers will no longer require their physical presence at corporate headquarters in a distant city.

Instead, each participant will sit before a 3-D color camera in a booth at his home office. Relayed by satellite, the images of all the others are projected upon the curved wall of the booth, and their voices are heard. All have the feeling of being seated together in the same room, around the same table.

Letting the electrons and microwaves do the traveling will become the fashion of the eighties. In the long run it will help to reduce traffic congestion and air pollution; it could even contribute to abating the energy crisis and countering the troublesome trend toward ever more urbanization.

I have heard it said that if Alexander Graham Bell had waited until the advent of satellites and microwaves to invent the telephone, instead of stringing the globe with millions of tons of copper wire, he would have opted for switchboards in the sky. PS

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—Contents p. 6

The fascinating behind-the-scenes story of

The Rescue of Skylab

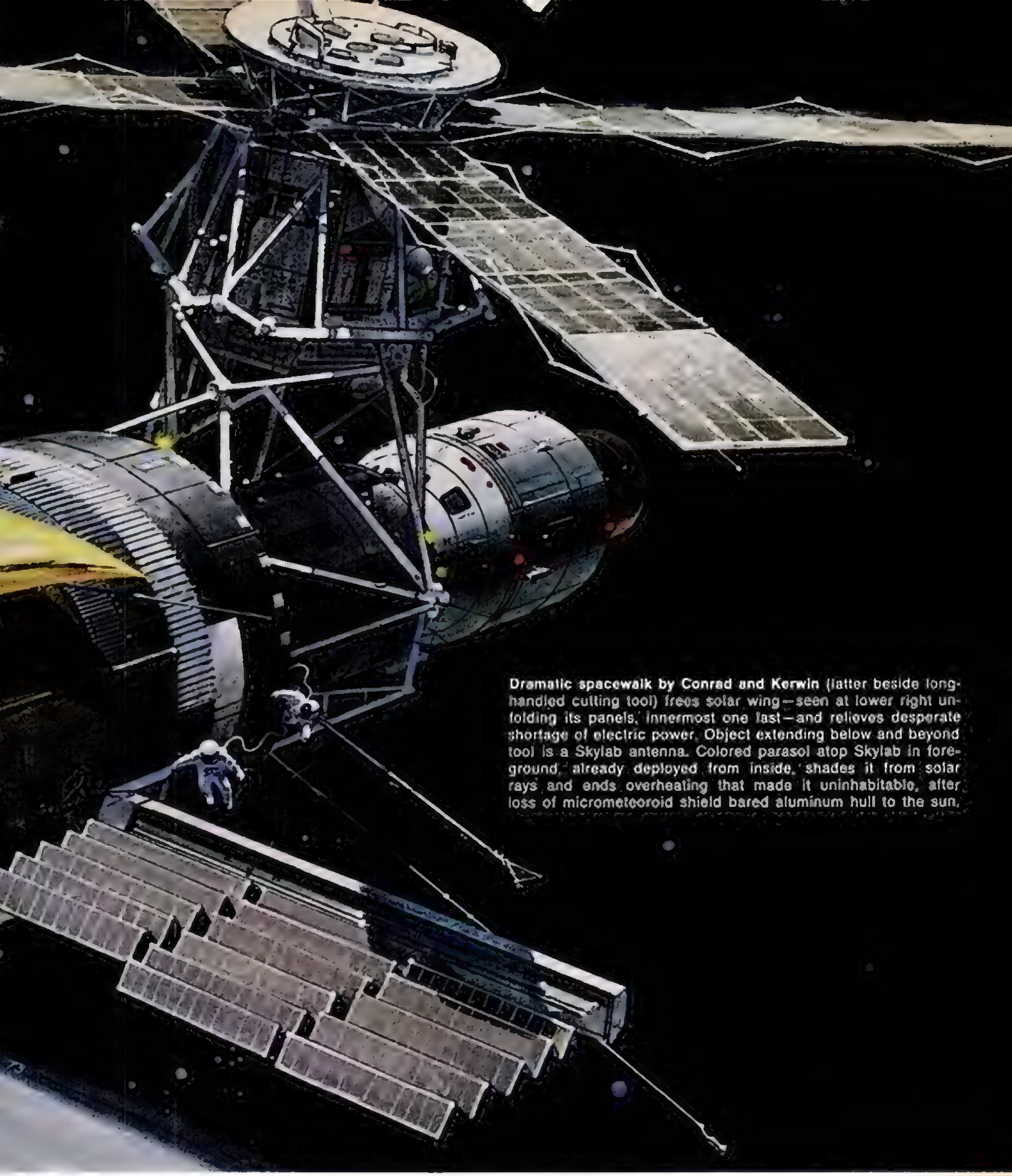
By WERNHER von BRAUN
PS Consulting Editor, Space

ILLUSTRATION BY BOB McCALL

Our second Skylab crew should now be back, and our third one preparing to go up this month or next.

Neither flight could have taken place, but for the spectacular space-repair feats of Skylab's initial crew—which put the first manned mission in a class by itself. Dr. von Braun's revealing account of it will give you, as it gave us, a new insight into what was happening as astronauts and groundlings raced the clock to save crippled Skylab.—The Editors

Around the world in 270-mile-high orbit, once every 93 minutes, sailed our first space station. It was the largest spacecraft ever built, 118½ feet long with its three-man crew's earth-to-orbit Apollo ferry attached. Twenty-four days after its launch, it could also claim to be our most patched-up, lopsided spacecraft—and claim it proudly, considering the emergencies that this inelegance had enabled it to survive.



Dramatic spacewalk by Conrad and Kerwin (latter beside long-handled cutting tool) frees solar wing—seen at lower right unfolding its panels, innermost one last—and relieves desperate shortage of electric power. Object extending below and beyond tool is a Skylab antenna. Colored parasol atop Skylab in foreground, already deployed from inside, shades it from solar rays and ends overheating that made it uninhabitable, after loss of micrometeoroid shield bared aluminum hull to the sun.

Incredibly, a huge, gaily colored parasol sprouted from its hull. One of its two main solar-power wings was spread to the sun, the other one missing. But the important thing was, Skylab worked.

By erecting the improvised parasol, and by extending a jammed solar wing in a spectacular spacewalk of more than three hours, Skylab's first crew saved the entire $2½-billion project from disaster. Their prowess as space repairmen put the stricken space station, seemingly hopelessly damaged in launching, back in order for their own 28-day mission and for the far-longer missions of two crews to follow.

They had helpers on the ground. Some invented and produced brand-new space hardware with unheard-of speed. Others perfected unprecedented spacewalk maneuvers, in a huge underwater tank. This is the story of how the combined endeavors rescued Skylab.

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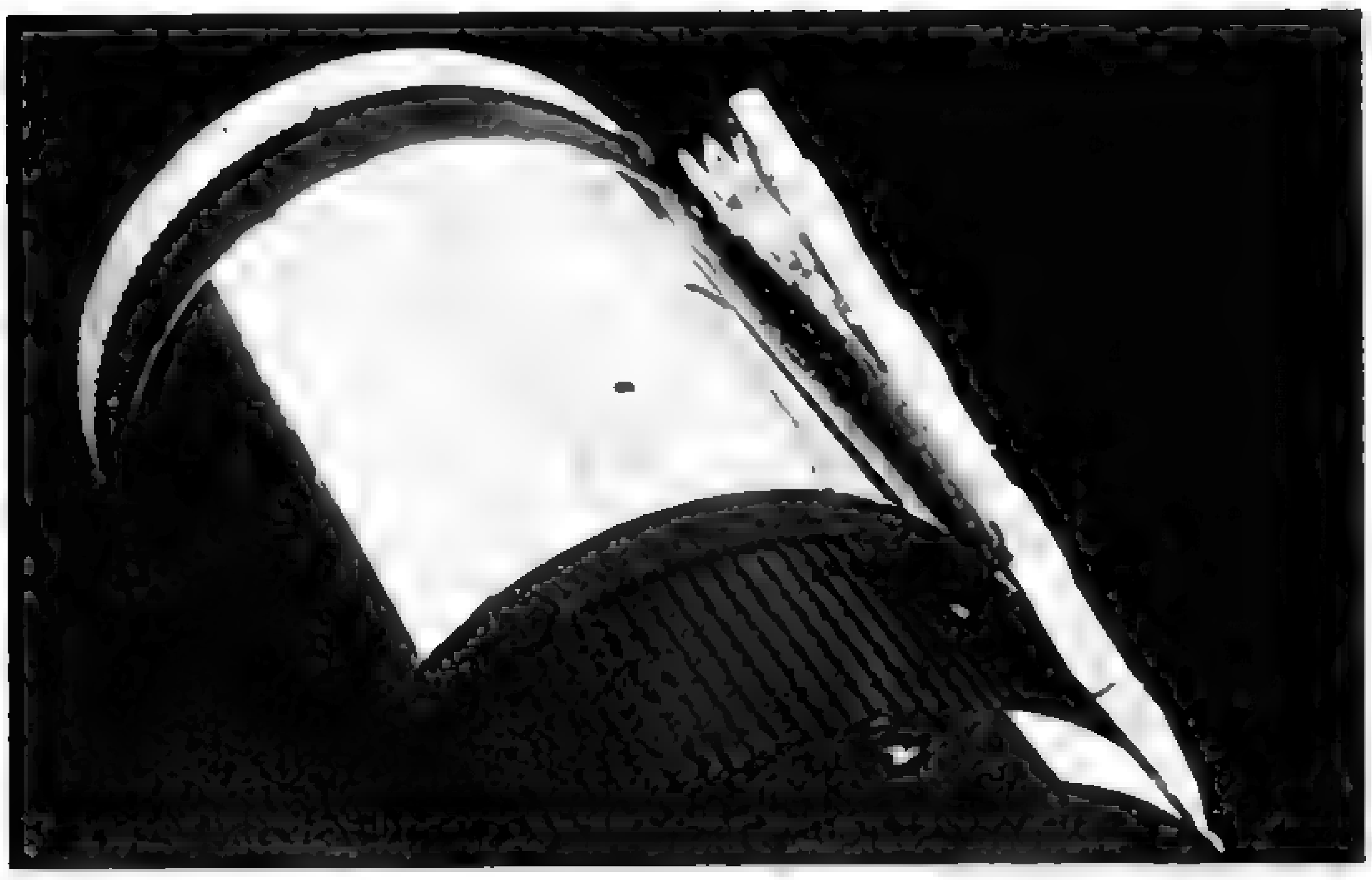
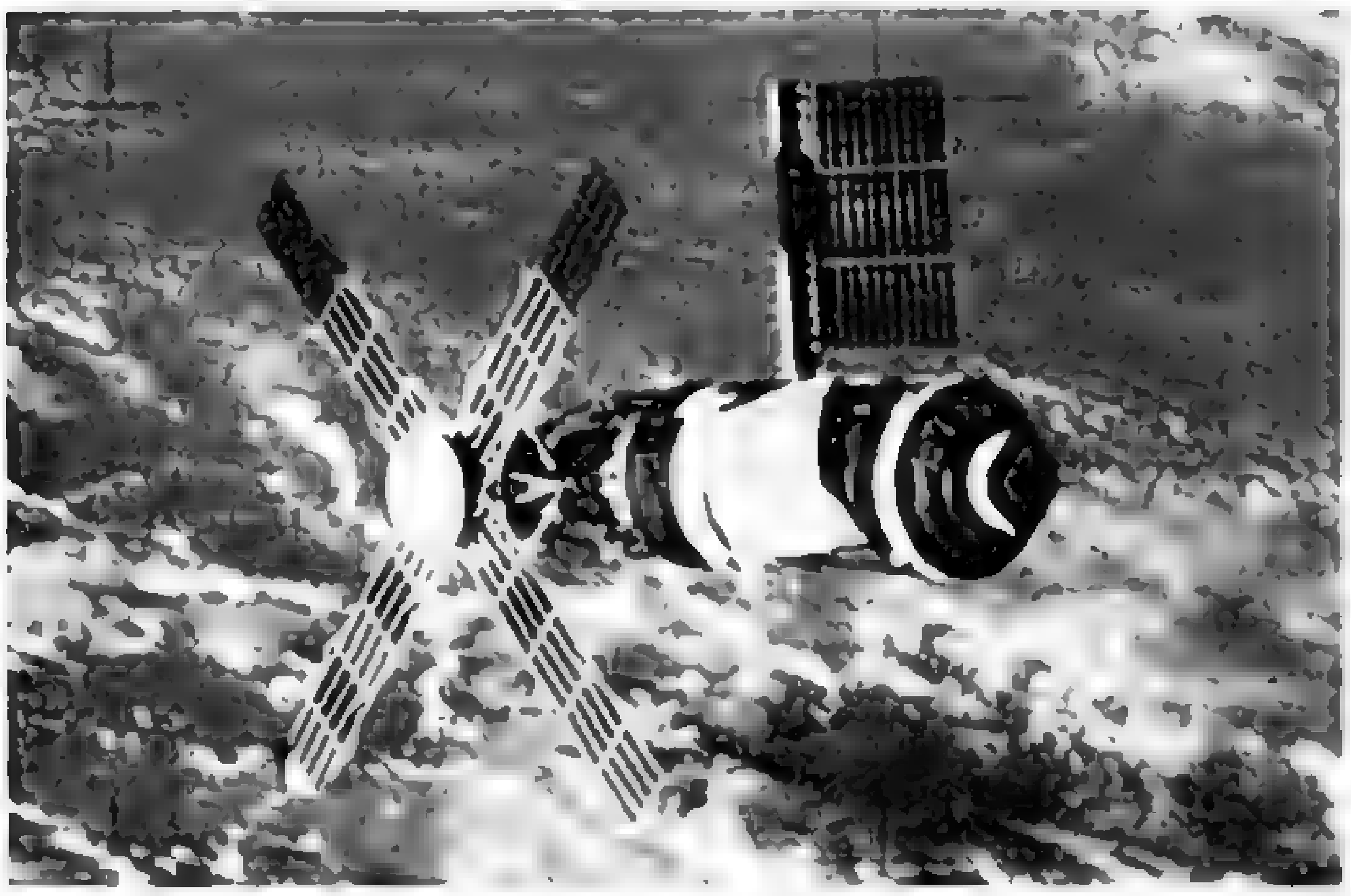
Repairing a stricken space station in 270-mile-high orbit opens the way



Before repairs, jammed solar wing is seen barely opened, at right of Skylab's cylindrical Orbital Workshop, in photo made during Apollo "flyaround." Compare later view, below.



After repairs, freed wing is fully extended (above Skylab). Departing crew's photo also shows parasol (white patch), and windmill-like solar arrays of Skylab's telescope mount.

Cutting tool that released solar wing is displayed, left, by backup crewman Rusty Schweickart. He and a teammate rehearsed spacewalk to do job on Skylab mockup submerged in huge tank, below, at Marshall space center, to simulate zero g. Floats made the tool "weightless."

Launched in one piece. Skylab was orbited unmanned, but completely assembled, last May 14. Joined end to end were three sections: a Multiple Docking Adapter where a crew would park its Apollo craft during its stay; an Airlock Module with a hatch for spacewalking; and an Orbital Workshop, the largest section, a two-story central laboratory and living quarters converted from a Saturn V third stage. A solar-observatory tower, the Apollo Telescope Mount, would pivot out sideward from the Multiple Docking Adapter after Skylab reached orbit.

A key ingredient of our story: Skylab was our first solar-powered manned spacecraft. Two wing-like solar arrays, on opposite sides of its Orbital Workshop, were to be hidden during ascent within two hollow beams—held down alongside Skylab like the arms of a soldier standing at attention. In orbit they were to swing out, on radio command, as if the soldier raised his arms to shoulder height. Then panels of solar cells, folded accordion-wise in each beam, would unfold alongside the Workshop. The two 28-by-30-foot solar wings, the largest ones ever flown in space, would furnish more than half of Skylab's electric power. The rest would come from a windmill-like solar-array cluster on the Apollo Telescope Mount.

The huge Skylab was launched by a two-stage Saturn V rocket. A smaller Saturn IB was to boost its first crew up to it the next day. Fate ruled otherwise.

Trouble struck fast. Only 63 seconds after liftoff, Skylab was in big trouble. It was coming apart.

At about 40,000-foot altitude, the supersonic slipstream tore away the Orbital Workshop's micrometeoroid shield—a thin flexible shell of aluminum, intended to lie tight against the hull during launch, and then to be extended five inches by torsion bars.

Wreaking havoc, the wind-whipped debris jammed one solar wing. It broke tie-downs of the other wing—which, opening prematurely, was ripped completely off.

First inkling of this came when Mission Control in Houston commanded orbiting Skylab to open its wings—and nothing happened. From the Orbital Workshop's solar-wing system came a puny 25 watts, instead of expected thousands. An analysis of Skylab telemetry from liftoff to orbit told what might have occurred.

In a pinch the Apollo Telescope Mount's "windmill" could spare power to the Workshop. Even a crew's Apollo could contribute a little from its fuel cells. But Skylab's supply for spacecraft operation and for science experiments was grievously curtailed.

Heat wave in Skylab. Worse was to come. The lost shield would have shaded the Workshop from the sun's fierce glare in space. Without it, the interior's temperature shot up past 120 degrees—and Skylab's living quarters became uninhabitable. That did it.

Out the window went NASA's script for the first crew's mission. Instead, for the first time, a crew would go up to try to repair a disabled spacecraft.

Skipper of the all-Navy crew was Capt. Charles ("Pete") Conrad Jr., 42, veteran of Gemini 5 and 11 and Commander of Apollo 12. His shipmates were Comdr. Joseph P. Kerwin, 40, full-fledged M.D. and the first medical spaceman; and Comdr. Paul J. Weitz, 41. In that order the three bore a Skylab crew's titles of Commander, Science Pilot, and Pilot.

Their launch was postponed five days, then five more, to equip them for their revised mission. But time was running out. Food, medicines, and films for three successive crews would soon spoil aboard the ovenlike craft. The heat even threatened to poison Skylab's two-gas oxygen-nitrogen atmosphere, with toxic

Running around Skylab wall is new space sport. Centrifugal force enabled crew to stride erect after start shown (by TV) from toeholds between lockers in ring around wall.

First showers in space refreshed Conrad, above, and his crewmates. Skylab shower has pushbutton spray and vacuum system to collect and dispose of the droplets of water.

fumes baked from polyurethane-foam wall insulation.

Rigging a makeshift sunshade to cool the overheated Workshop was the crew's most urgent task. They carried alternate versions—the most favored, a parasol designed and built in six days at Houston, which arrived barely in time for their May 25 launch.

First look at crippled Skylab. When the crew rendezvoused with Skylab, 7½ hours after liftoff, a "fly-around" inspection confirmed NASA's diagnosis of the damage. Where one solar wing had been, only bits of jagged metal and dangling wires remained. The other wing, snagged around its beam by an aluminum strip from the torn-off shield, had barely opened—accounting for the 25 watts reported by telemetry.

From their Apollo, the crew made a daring attempt to free the stuck wing. Conrad piloted the craft so close to Skylab that Weitz could lean out of the opened hatch and yank at the strip with a 10-foot tool shaped like a shepherd's crook. Nothing budged. They couldn't open the wing with the tools they had, they reported. (Better luck would come about two weeks later.) They docked to Skylab, and slept in Apollo.

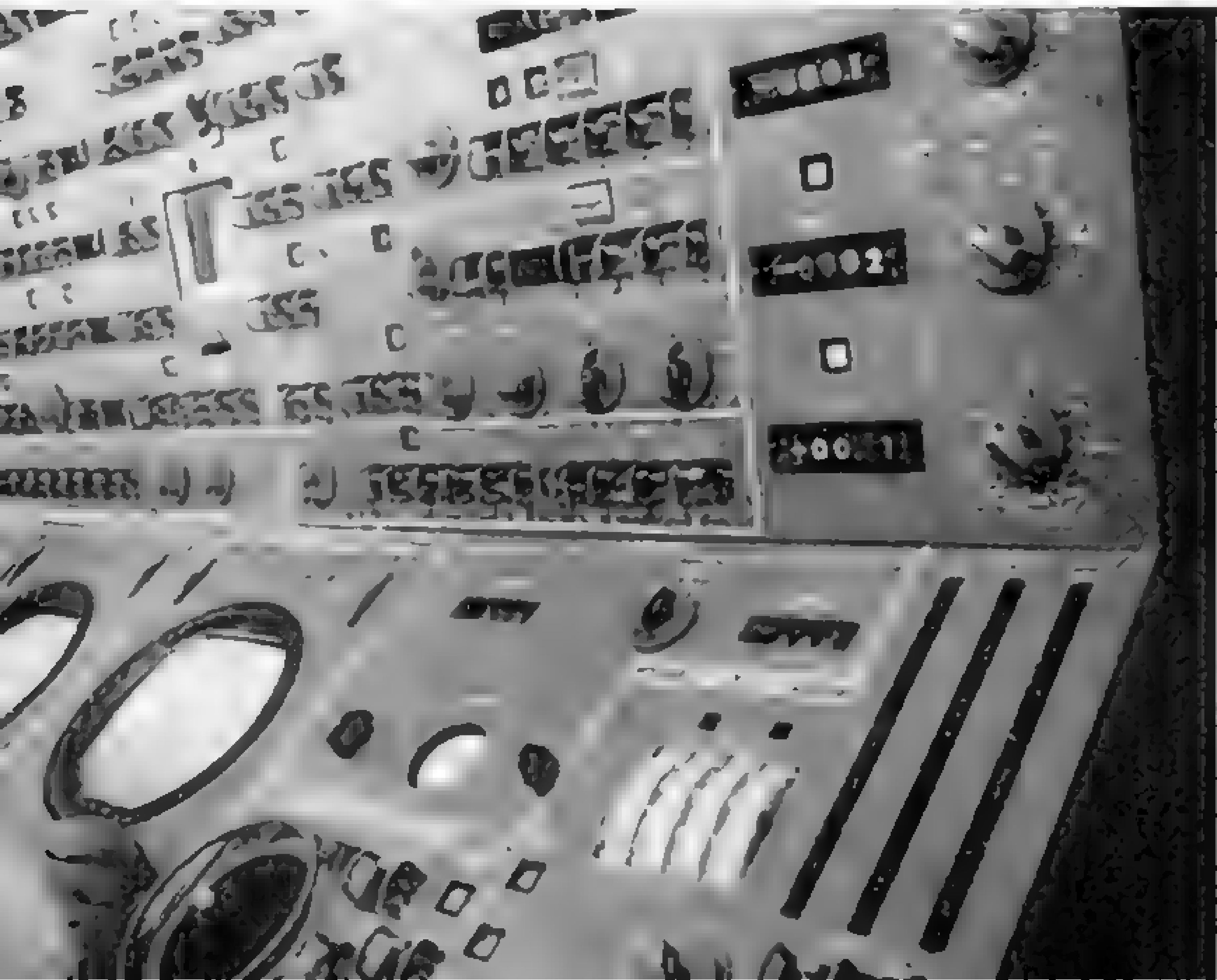
First to brave Skylab's heat next day was Weitz—wearing a gas mask in case toxic fumes lingered in the craft's atmosphere after repeated venting. There weren't any, a chemical test showed. Weitz started fans to make the Workshop's temperature bearable, and he and the others lugged in Houston's parasol. It was first choice for a sunshade because it could be deployed from inside Skylab, avoiding the hazards and difficulties of spacewalking.

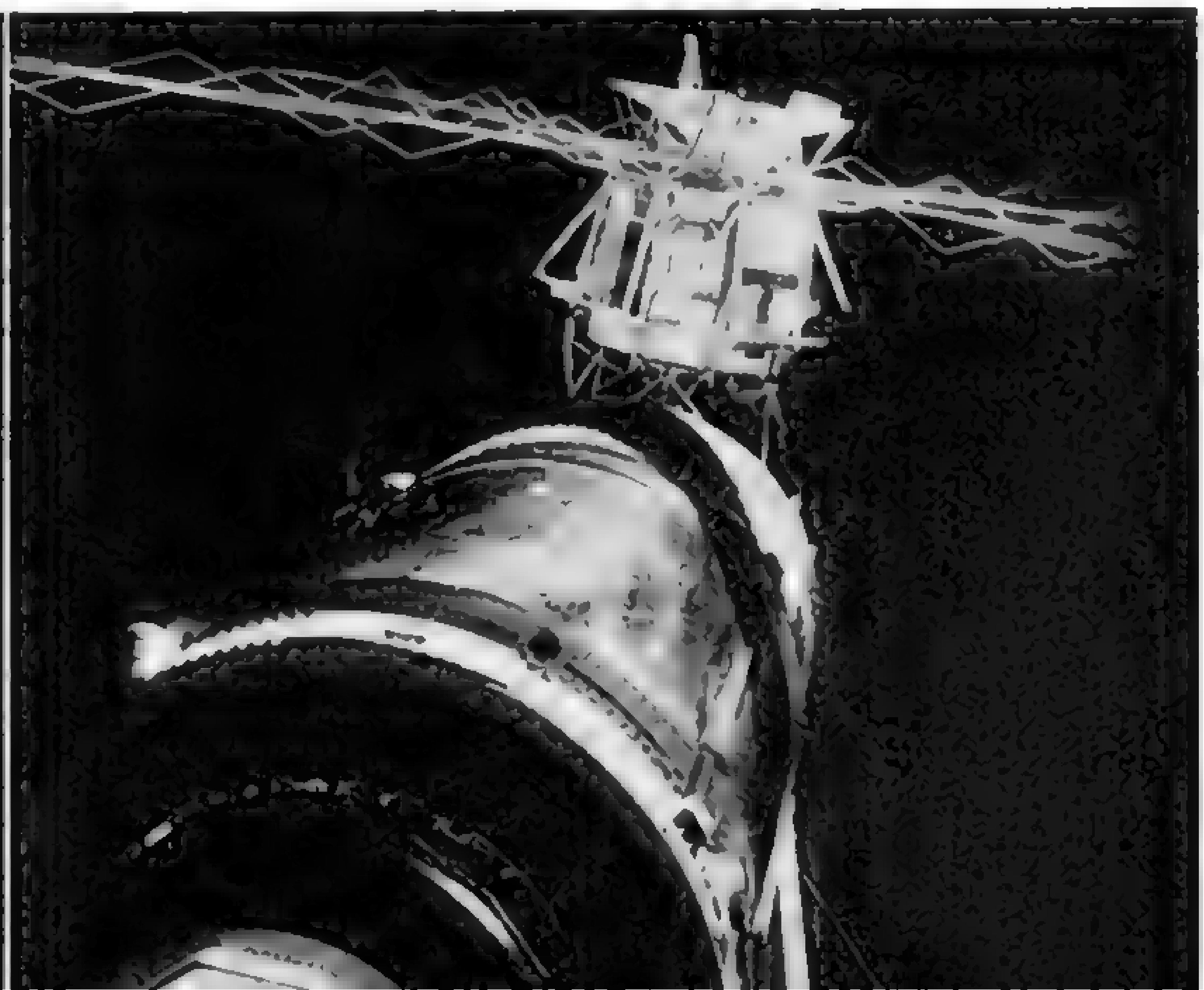
Up goes a parasol. The crew pushed out the folded parasol through an 8¼-inch-square opening in the Workshop wall called a "scientific airlock," designed to expose experiments to the vacuum of space. Adding sections to a "handle" raised the parasol until it cleared the hull. Then it unfolded into a rectangular 22-by-24-foot canopy shading the Workshop—and was drawn back close to the hull and secured there.

The parasol's fabric was nylon cloth of high-visibility golden hue, laminated to metallized Mylar film. It remained a bit puckered up, but it did the trick. Gradually the temperature in the Workshop fell. The crew could sleep in it by May 29; within another week, their quarters' temperature leveled off in the reasonable mid-seventies. (Spots where they went to cool off meanwhile were Skylab's docking and airlock

[*Continued on page 170*]

Down-to-business work of first Skylab mission included making 30,000 photos of sun with station's $121-million solar-telescope array, operated from console (left) in docking section. Miniature joystick at bottom is manual pointing control. Telescope array itself, pictured in orbit (right), extends at right angles to rest of Skylab space station.





The Rescue of Skylab

[Continued]

space sport of running around the Workshop's 22-foot-diameter wall. Debated before the flight was whether the centrifugal force would give them enough artifical g to stride erect. It did.

The aftermath. These things followed the first Skylab mission:

- A new sail-like sunshade was spread over the hastily contrived parasol, by the second crew, in a spacewalk well practiced by then.
- Skylab is the first space project to provide for crews' rescue—and that possibility arose, when leaks successively disabled two of four sets of thrusters on the second crew's Apollo Service Module. If no more failed, study showed, safe return was still feasible. But, just in case, a five-man "rescue" Apollo was ordered readied. Two backup crewmen could fly it to Skylab and bring back a stranded crew.
- Lest Skylab have another power crisis, NASA would also ready a novel auxiliary Power Module, with two solar arrays exactly like the four of the telescope-mount "windmill." A crew's Apollo, handling it just like a moon mission's Lunar Module, could fly it up to a Skylab docking port—and plug it in to feed more power into the space station.

It would be carried aloft, if at all, on the third manned mission.

- A NASA board of investigation reconstructed what happened to Skylab during launch. To facts already noted here, it added that the lost solar wing came off about nine minutes after the shield accident, when it was hit by the blast of retrorockets that separated Saturn V's second stage. (Since Skylab by then should have reached orbital velocity, the missing wing is probably still in orbit.)

An unanticipated buildup of air pressure beneath the shield—due to "design deficiencies," the board found—forced it out into the wind stream to its destruction.

But it took no official report to make the outstanding lesson of the first Skylab mission come through loud and clear:

Man in space saved the day. He demonstrated to doubting Thomases his ability to take charge and put things to rights in a situation where an unmanned spacecraft would rapidly turn into a helpless piece of orbiting junk. Skylab's striking lesson of man's value in space will not be lost on planners of future space projects. An example: possible revision of Space Shuttle designs to allow more spacewalking in case of need.

Tune Your Heating System

[Continued from page 128]

should be 70 degrees and the minimum 40 degrees. If your measurements don't fall within specifications, they're easily corrected by adjusting the blower speed.

Two types of blower motors are used on most furnaces: belt drive and direct drive. The belt-drive type will have an adjustable pulley on the motor shaft. The diameter of the pulley can be increased by loosening the allen screw on the movable sheave and turning it clockwise. It can be reduced by opening the sheave. Increasing the blower speed by increasing the diameter of the motor pulley will result in a reduction of temperature rise across the heat exchanger.

When direct-drive blowers are used, the squirrel-cage fan is mounted directly to the motor shaft. Often these motors have tapped windings that allow as many as five variable speeds to be selected simply by moving a wire on the terminal board. A diagram should be pasted inside the terminal-board cover or on the furnace, showing you which windings control the various speeds of the blower. Select the one that gives you the proper air temperature rise for your installation.

Setting controls. For maximum efficiency, it's wise to consult your furnace manual for the manufacturer's recommended settings and be sure that they are adjusted accordingly. If you haven't opted for CAC (see box) on a warm-air system, then you may want to realize some advantage by reducing the temperature setting of the fan control. This thermally-operated switch determines the temperatures at which the blower turns on and turns off, and chances are it may be desirable to set it lower than its current position. Rather than turning the blower on at 135 degrees and off at 115 degrees, you can just as easily turn it on at 100 and off at 80. The moving air may feel cool if you place your hand directly in front of a register at these lower cutoff points, but the air input into the house is still quite a bit warmer than room temperature actually is.

On hot-water systems there is an adjustable control for the temperature of water in the water jacket of the furnace. Lowering this won't improve efficiency, however, since the circulation of the water is controlled directly by the thermostat.

The limit switch on forced-air and hot-water systems is a safety device and should always be set exactly where the manufacturer recommends it. Under normal conditions it won't ever come into operation. It's simply there to prevent damage to the furnace in case something goes wrong with the circulation system.

Be sure that your furnace room or crawl space is not sealed so tightly that insufficient combustion air is available for the burner, reducing efficiency by "starving" the flame because of a lack of oxygen. The owner's manual supplied with your furnace will give specific requirements, but a rule of thumb is to provide one square inch of ventilation to outside air for each 1000 Btu's furnace capacity. For example, a 100,000 Btu furnace would require a 10-by-10-inch opening. This can usually be provided simply by leaving a vent or two open, or by installing a grille in an outside wall.

What an expert should do. Combustion testing is the one sure way to be certain that you're getting all the efficiency from your gas- or oil-fired system that your installation and design limitations will allow. The tests require special instruments and knowhow. These involve measuring draft, CO_2 content, and the amount of smoke present in flue gases. The technician can use these test results to obtain the maximum design efficiency by correcting any problems that exist. He'll examine the flame pattern with a special metallic mirror. It's likely that he may want to change the nozzle and/or burner adjustments.

In some cases it might be wise to ask about "underfiring" the furnace—reducing the firing rate by reducing burner nozzle or orifice size. Since most residential furnaces are oversize, this can sometimes result in a small fuel savings, and can also add to comfort. If, on the coldest day during the winter in your area your furnace is still cycling on and off, chances are that it's larger than it needs to be. Don't try to reduce input more than 20 percent—the chances are that the heat exchanger will run too cool and premature rusting may result.

If your furnace is over 10 years old, there are possibly some new accessories that may help to improve efficiency. Modern oil nozzles have been scientifically tested and designed to squeeze the maximum Btu's from each drop of oil and new gas burners use every trick of mixing gas with air to obtain maximum benefits. But the little valve to bolt onto your heating plant that will reduce its fuel consumption by half still doesn't exist.

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Popular Science

THE What's New MAGAZINE

Before You Buy: A SHARP LOOK AT THOSE NEW ELECTRIC SHAVERS

NEW CATALYTIC CARB
Cracks Gasoline into Clean-Burning Gaseous Fuel

How Pioneer 10's Clever New Sensors Will Unveil
MYSTERIES OF THE PLANET JUPITER

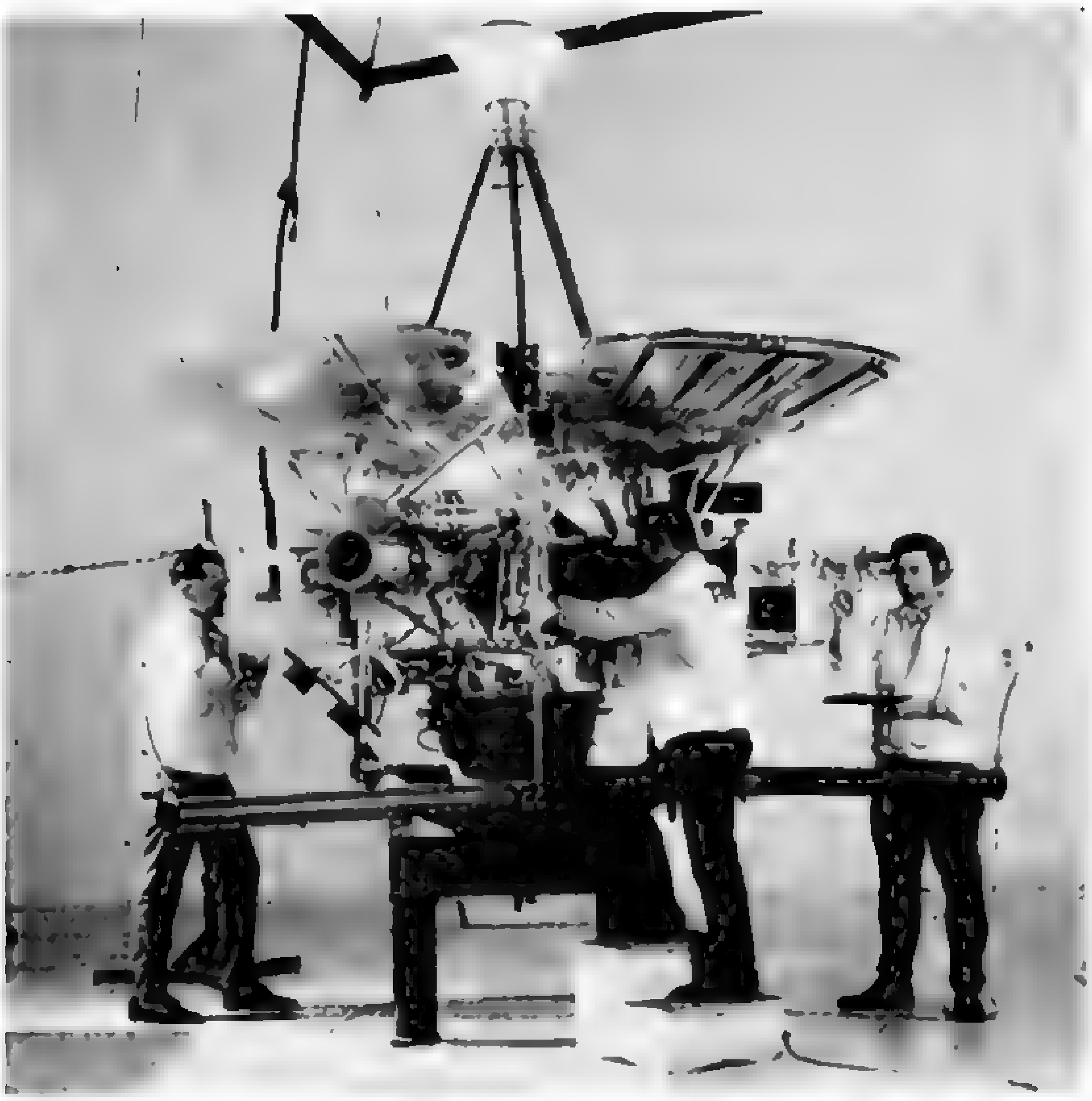
EARTHQUAKES
Now Science Can Predict When and Where They'll Happen

Testing Three
SUPERCARS
What Are Their Secrets?

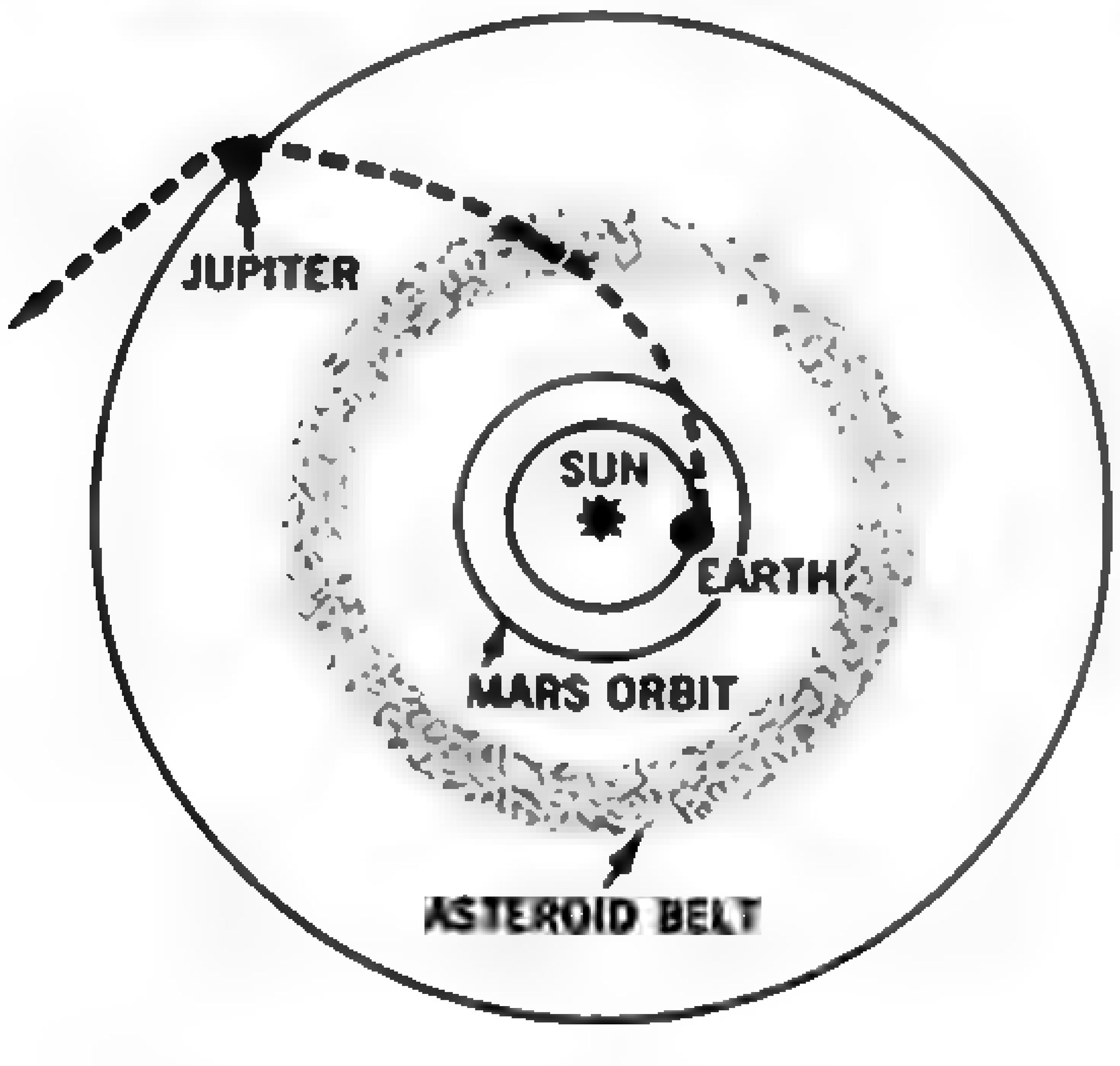
H... TRAINS
"R... on
P... eep you well-informed

Mysteries of the giant planet with the Great Red Spot may be solved when our Pioneer 10 spacecraft whizzes past this month within one-diameter range

Our First Close Look at

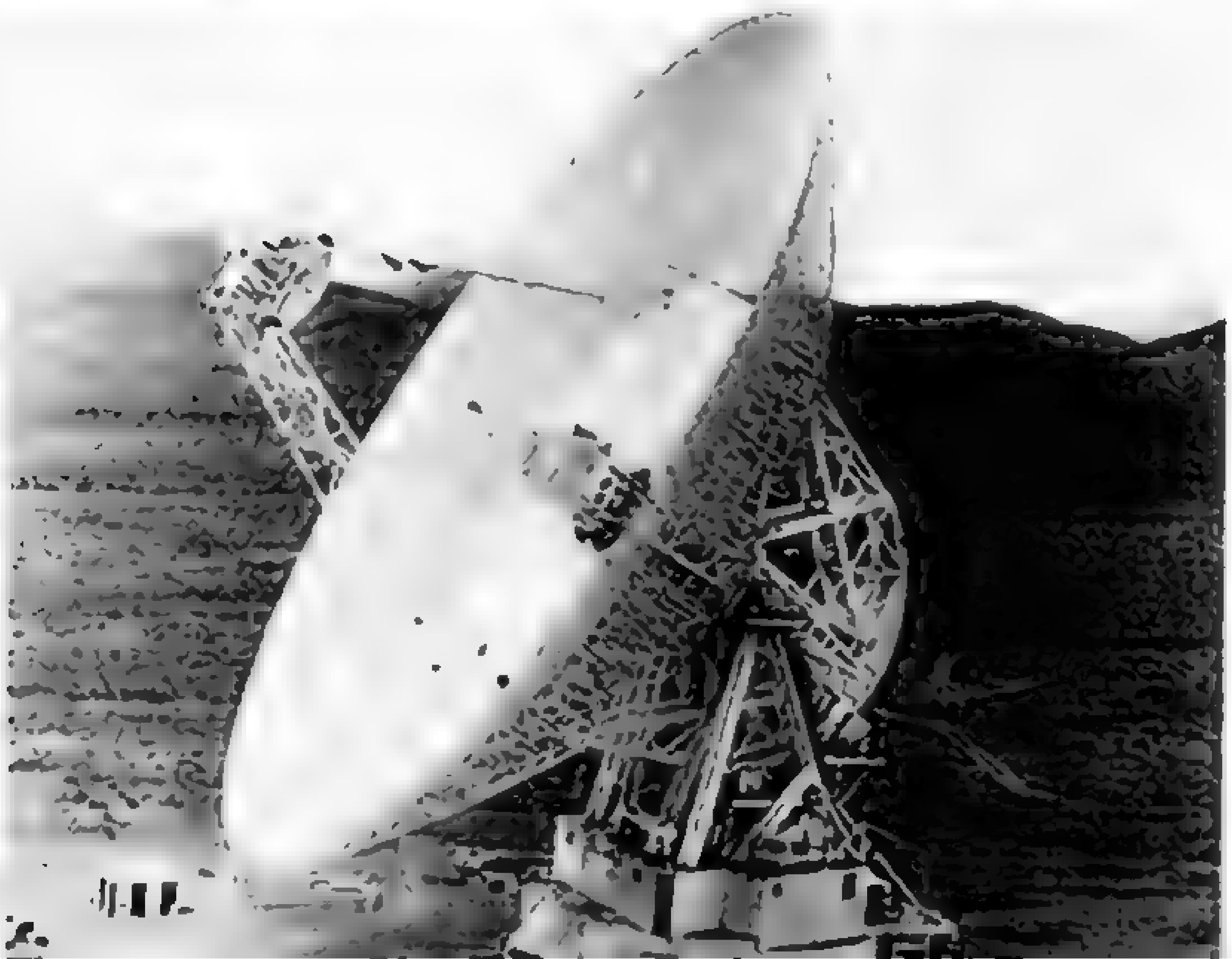


Pioneer 10 is readied by TRW technicians for ½-billion-mile voyage to Jupiter, arriving this Dec. 3. Nine-foot-diameter dish antenna will transmit to Earth what it sees.



Course to Jupiter of Pioneers crosses Mars' orbit and Asteroid Belt, as shown. Pioneer 10 will swing wide of Saturn, but Pioneer 11 may be targeted to pass close to it.

Pioneers' reports on Jupiter will come in to 210-foot-diameter antennas like this big dish at Goldstone, Calif.



By WERNHER von BRAUN
PS Consulting Editor, Space

This month a 1¾-year space voyage of more than a half-billion miles reaches its objective, and the exploration of the outer solar system begins, when a saucer-shaped NASA spacecraft flies past the gigantic planet Jupiter and its bevy of a dozen moons.

At nearest approach, on December 3, Pioneer 10 will skim within 81,000 miles of Jupiter—even closer than the maximum 88,900-mile diameter of the sun's biggest planet. From about 50 hours before to 50 hours after, its observing gear will go into all-out action.

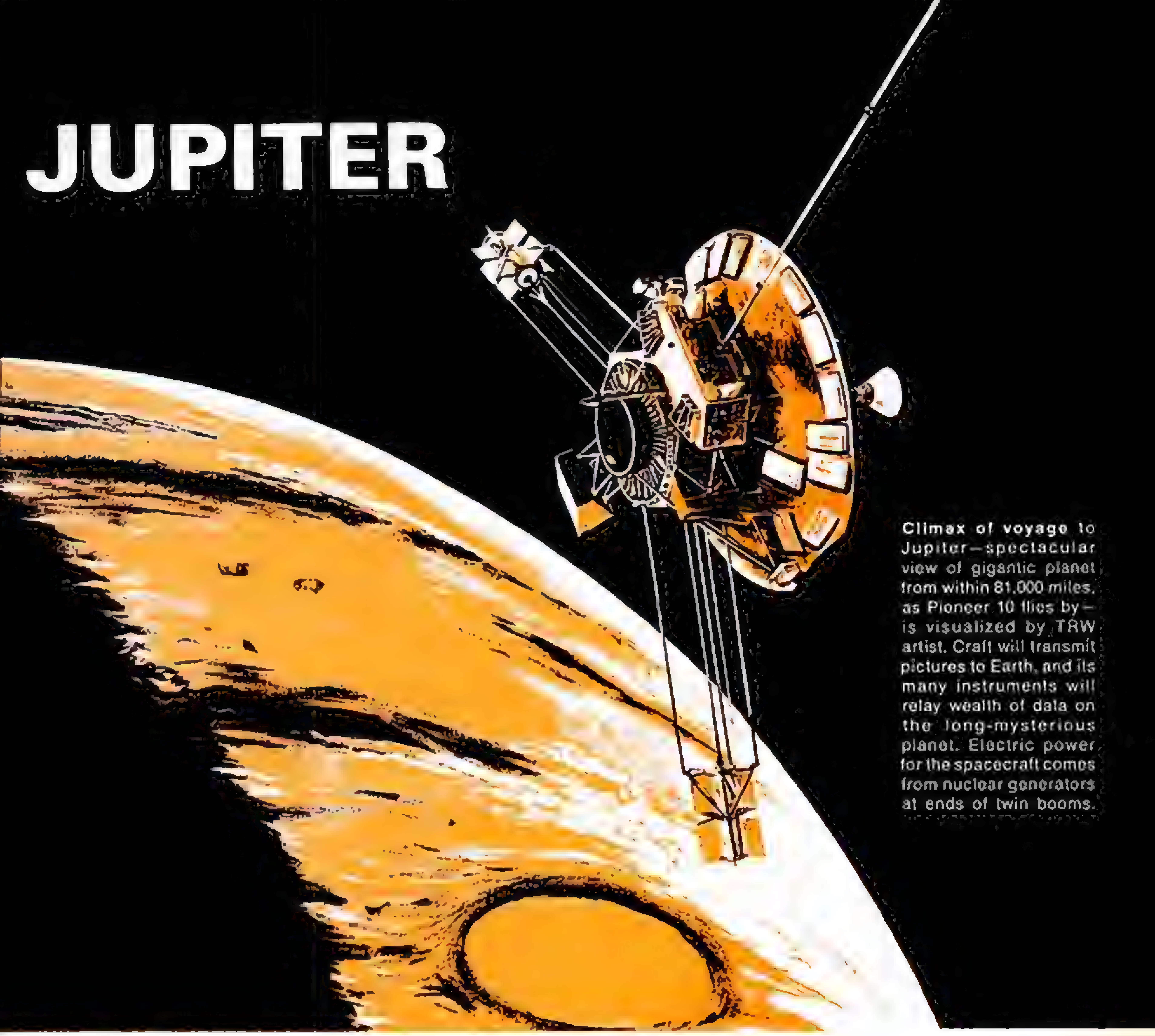
First close-up pictures of Jupiter and its mysterious Great Red Spot are to be sent to Earth by an unconventional "camera" on the unmanned spacecraft. Instruments will seek answers to other riddles of a world whose exotic make-up rivals fantasies of science fiction. For example, Jupiter may consist largely of a metal never seen on earth—metallic hydrogen. Its atmosphere contains such strange constituents as methane (marsh gas) and ammonia—and excites students of our own Earth's past because it may be a surviving, observable counterpart of the Earth's primitive atmosphere around the time when terrestrial life began.

The Jupiter spacecraft. The space mission of Pioneer 10, built for NASA's Ames Research Center by TRW Systems, is the farthest ever attempted by man. So high are the propulsive requirements, 10 times as much energy per pound of spacecraft as for our 1971 Mariner to Mars, that the craft is necessarily small. Its 570-pound weight at launch was barely more than a quarter of the Mars Mariner's 2272 pounds. Its spartanly limited payload capacity for instruments totals only 66 pounds, against the Mars craft's comparatively lavish 150 pounds. But designers have met the challenge, with an array of exquisitely ingenious lightweight observing devices—consuming, all told, less power than a single 25-watt bulb!

A nine-foot-diameter dish antenna, to transmit its pictures and instrument readings back to Earth, dominates the exterior appearance of Pioneer 10. A tripod above the dish supports a small wider-angle antenna, for less-extreme range. Below the dish is the craft's hexagonal hub, with a boxlike instrument compartment attached to one side. Conspicuously absent is any such windmill-like array of solar panels as on our Mars spacecraft. The sun's rays are so feeble at Jupiter's distance that a prohibitive number of solar cells would be required. Instead, Pioneer 10 draws its electric power from an atomic source—plutonium-fueled radioisotope thermoelectric generators (RTGs) at the ends of two extending booms. They meet its maximum requirements of 108 watts of electricity.

A new three-stage rocket combination, an Atlas-Centaur plus a Thiokol solid-propellant third stage, launched Pioneer 10 in March 1972 at a record 32,000 mph. That was the velocity required for a journey so far that the signals of the craft's eight-watt radio transmitter will take almost 46 minutes to reach us from Jupiter, over the straight-line communication distance of 500 million miles. Pioneer 10's curving elliptical

JUPITER



Climax of voyage to Jupiter—spectacular view of gigantic planet from within 81,000 miles, as Pioneer 10 flies by—is visualized by TRW artist. Craft will transmit pictures to Earth, and its many instruments will relay wealth of data on the long-mysterious planet. Electric power for the spacecraft comes from nuclear generators at ends of twin booms.

route will actually have taken it a lot farther, 620 million miles, to get there.

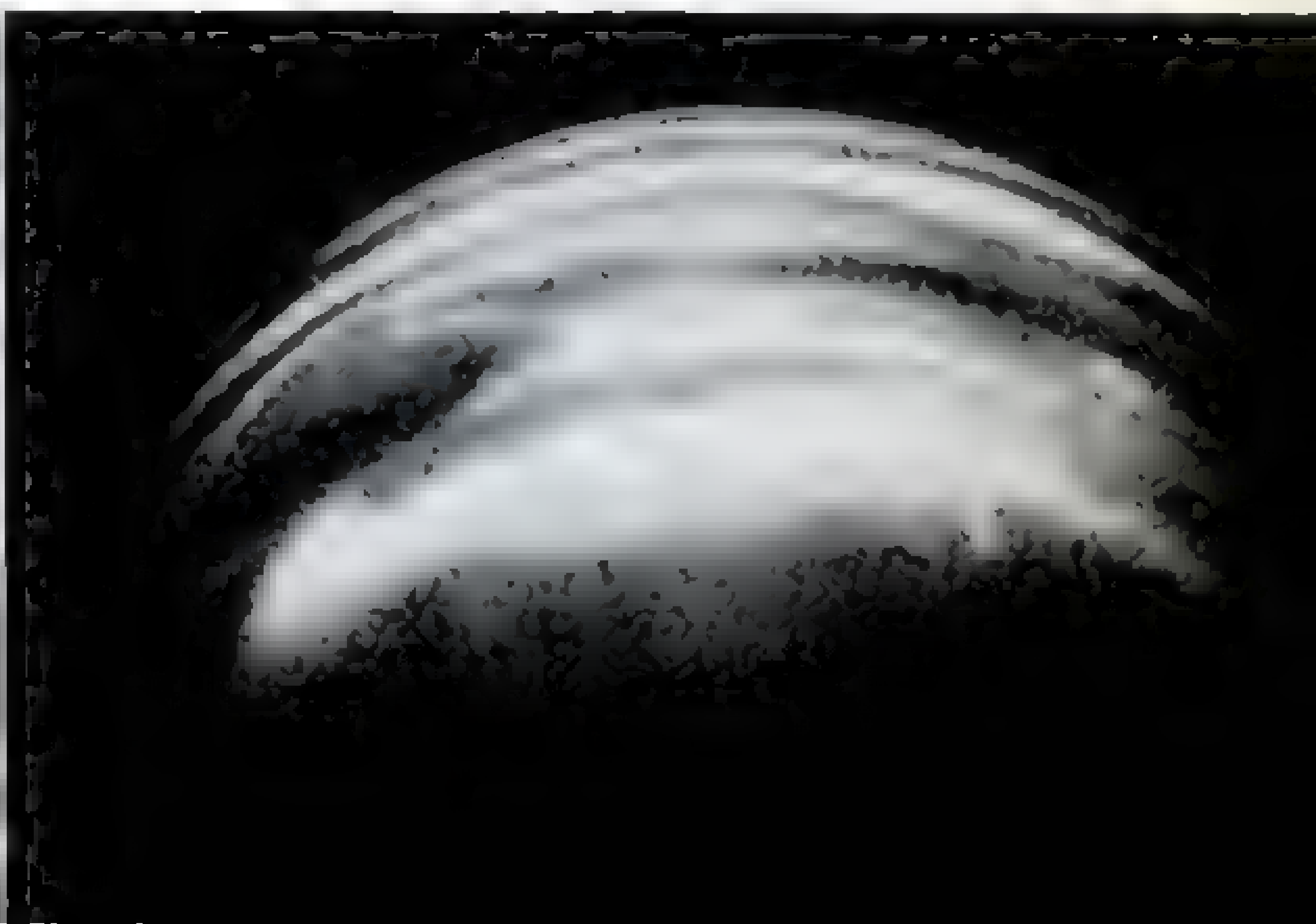
The view from Pioneer. As Pioneer 10 nears its target, Jupiter will swell to an eye-filling orb of awesome magnitude, exceeding 40 degrees in angular diameter—some 80 times as big across as the full moon seen from Earth. As if graciously obliging a visitor who's come so far to see it, Jupiter will pirouette for inspection, making 10 complete revolutions during Pioneer 10's climactic 100 hours of observation; despite the planet's enormous bulk, it spins around in nine

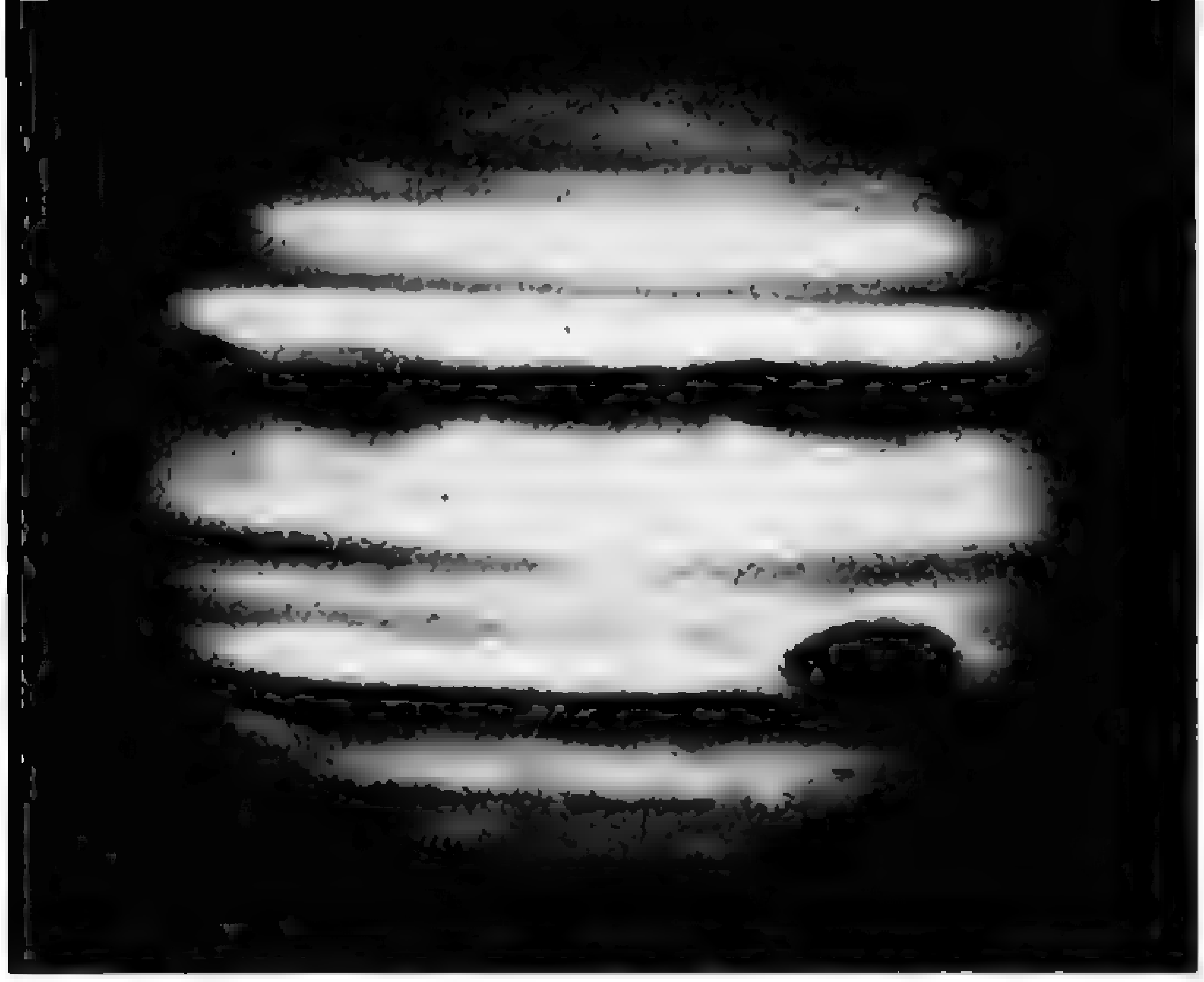
Continued

"Camera" of Pioneer 10, called an imaging photopolarimeter, is a sophisticated nine-pound instrument. (Photo from Santa Barbara Research Center.)

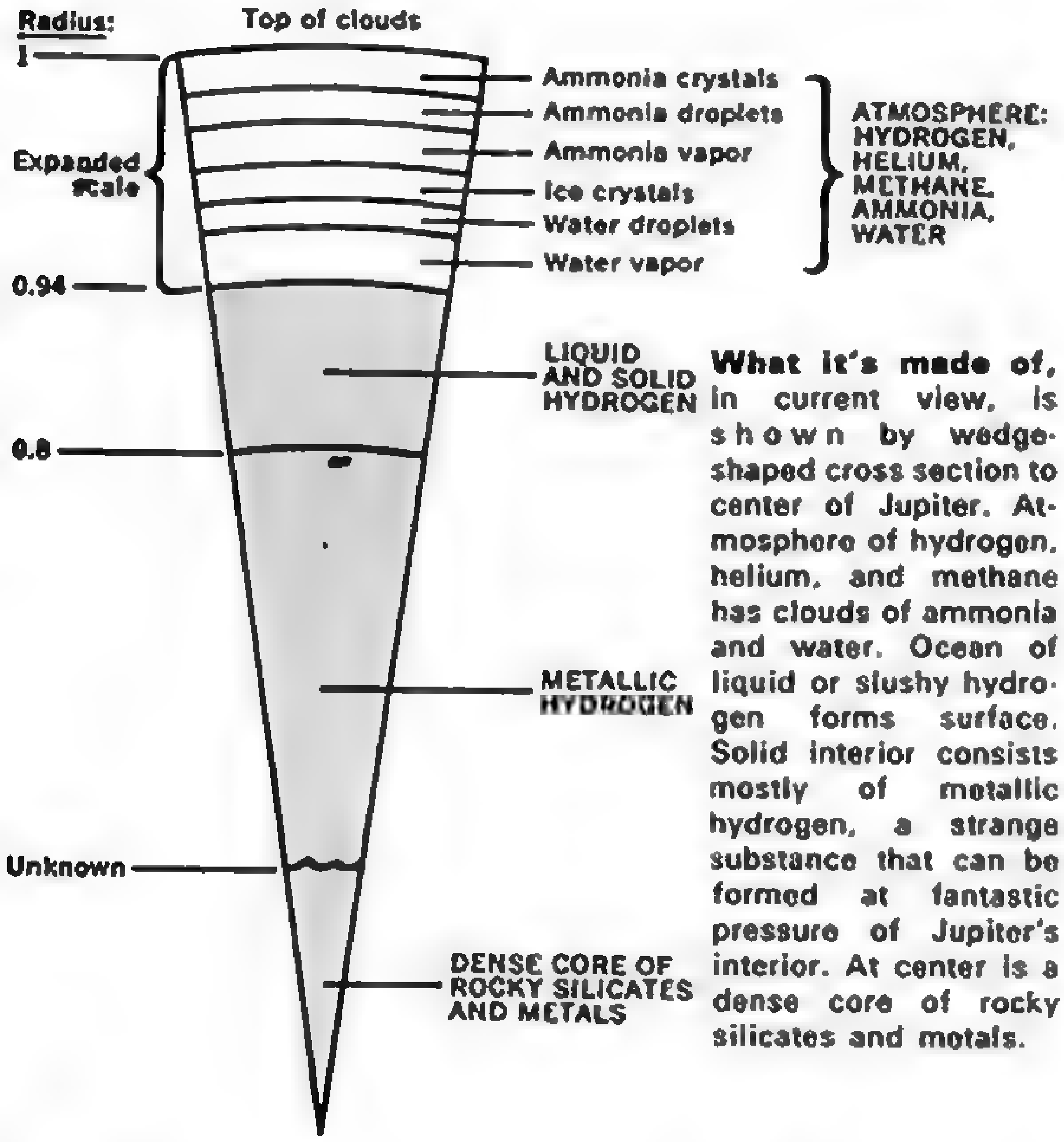
Pre-mission ground test of "camera" for Pioneer, at University of Arizona, produced photos of needed quality, like this one of optical-sciences building.

Simulated Pioneer photo of Jupiter, from NASA, gives preview of what actual pictures may look like. Details only 120 miles wide should be revealed.

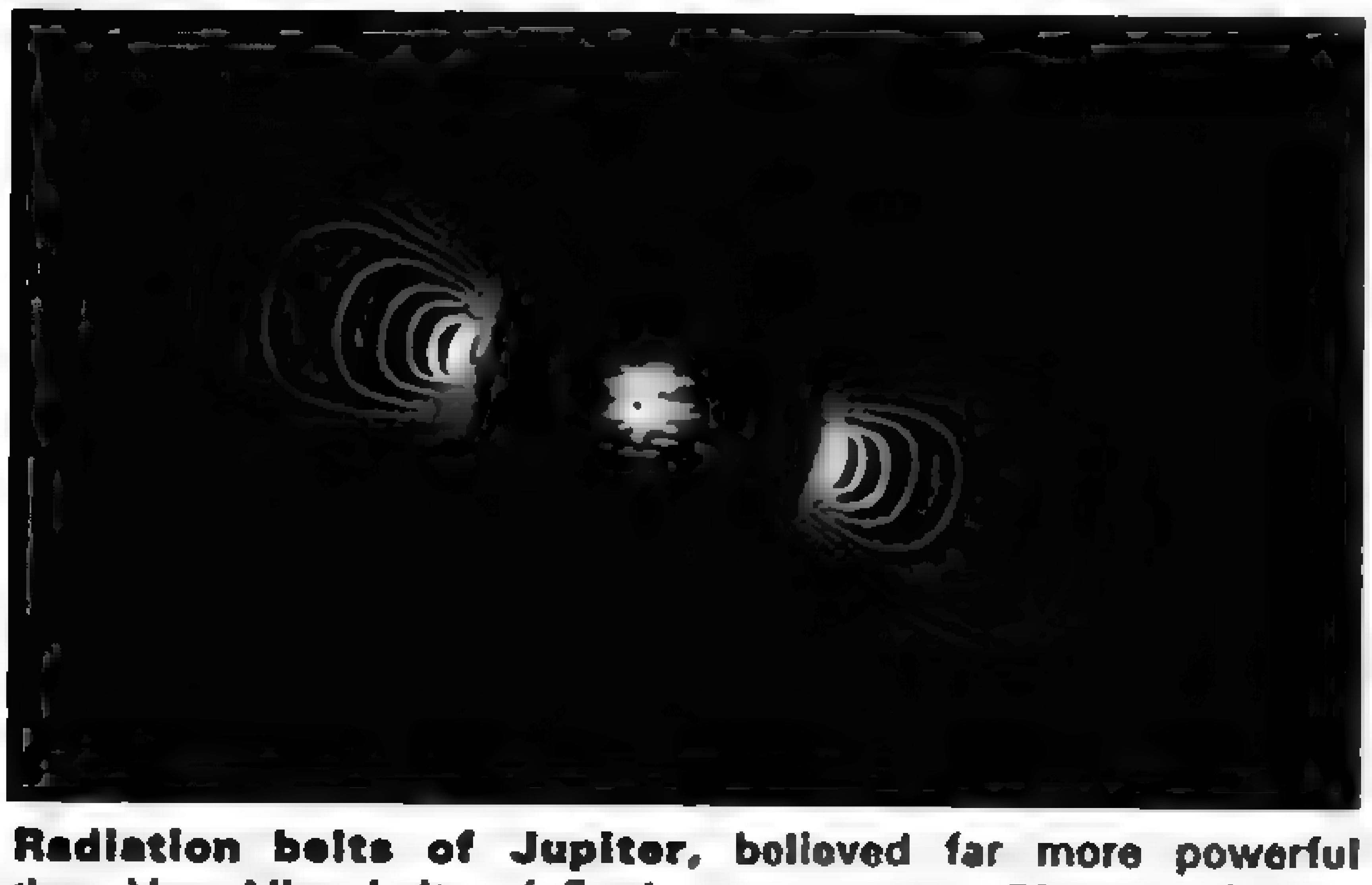




Mysterious Jupiter, viewed from Earth with 200-inch telescope, has distinctive pattern of multicolored bands. Oval-shaped blotch at its lower right is the Great Red Spot.



What it's made of, in current view, is shown by wedge-shaped cross section to center of Jupiter. Atmosphere of hydrogen, helium, and methane has clouds of ammonia and water. Ocean of liquid or slushy hydrogen forms surface. Solid interior consists mostly of metallic hydrogen, a strange substance that can be formed at fantastic pressure of Jupiter's interior. At center is a dense core of rocky silicates and metals.



Radiation belts of Jupiter, believed far more powerful than Van Allen belts of Earth, may menace Pioneer 10's instruments. If so, Pioneer 11 could give them wider berth.

hours and 55 minutes, less than half of Earth's 24 hours.

If you could be aboard the craft, you'd enjoy a spectacular view of features glimpsed before only through far-off telescopes. You'd see that Jupiter's face, golden in overall hue, actually has parallel stripes of bizarre and changeable colors. Sometimes there are slate-blue and pink bands; again, they may be gray, yellow, and orange. [Being in monochrome, the "fly-by" picture on the preceding page of course is not realistic as to colors.—*The Editors.*] The fleeting tints are not on Jupiter's surface, but are windborne in its atmosphere. For clues to what makes them, Pioneer 10's pictures will be eagerly scanned.

Colorful and changeable, too, is Jupiter's most famous mystery—the oval-shaped Great Red Spot, some 30,000 miles long, in its South Tropical Zone. Brick-red or carmine when most conspicuous, it sometimes fades to a pinkish shade or gray and becomes faint. Since it wanders about in longitude (though not in latitude), it seemingly must be a floating disturbance, of some unknown kind. Scientists hope they will soon see the most revealing photographs of it ever made.

The "camera." Pioneer 10 will take its pictures with a diminutive instrument called an imaging photopolarimeter. Although it weighs only 9.1 pounds, in contrast with the Mars Mariner's 57-pound pair of TV cameras, its advanced technology promises well for its results. It will eye Jupiter through a pointable one-inch-aperture telescope that protrudes from the side of the spacecraft.

The craft's own rotation to stabilize itself in flight, at about five rpm, will cause the telescope to scan the face of the planet. Thus the instrument will build up television-like images of Jupiter. Like Pioneer's other instruments, it will transmit what it observes to Earth in the form of a stream of digits. From these numbers, technicians on Earth will be able to reconstruct pictures of Jupiter, both by red and blue light (a gauge to coloring), with sharp enough resolution to distinguish features 120 miles across.

Fly-by pictures of Jupiter's cloud patterns possibly may reveal wind speeds, convective motions, and symmetries in the flows—key data for investigating the planet's atmosphere and weather. That might help to test the validity of one of the most intriguing theories for the tinted bands—that the colors are those of *organic* chemicals, synthesized from the methane, ammonia, and water in Jupiter's atmosphere by lightning or sunlight. Organic chemicals of similar hues have been produced on Earth, by electric discharges and by ultraviolet light, in laboratory experiments with a simulated Jupiter atmosphere.

The presence of organic chemicals would be no proof of life on Jupiter—but, in an atmosphere believed like that of the primeval Earth, they could represent initial steps toward the appearance of life. So if Jupiter's colors really do come from organic chemicals, some believe, the simplest forms of life may already have appeared on that planet. Such primitive organisms might be suspended in certain layers of Jupiter's atmosphere, just as algae and protozoa are suspended in the Earth's oceans. Contrary to earlier belief that Jupiter was too cold to support life, recent opinion holds that some levels of its atmosphere may be as warm as a summerlike 80 degrees F.

Taking Jupiter's temperature. Facts will replace conjecture when two Pioneer instruments, an ultraviolet photometer and an infrared radiometer, map Jupiter temperatures and search for hot spots in its upper atmosphere. The variety of things they'll tell illustrates scientists' knack of deducing a wealth of information,

[*Continued on page 138*]

[Continued from page 72]

often in roundabout ways, from simple data:

- These instruments' findings may help to explain the Great Red Spot; indicate whether Jupiter has a polar cap; and reveal the temperature of its dark side.
- Many astronomers see signs that Jupiter radiates two or three times as much energy as it receives from the sun—but this amazingly starlike behavior, for a planet, has never been proved. Pioneer's infrared radiometer should settle it.
- Jupiter's hidden surface may not be a solid one, but a storm-tossed ocean of liquid hydrogen (the main fuel of our Saturn moon rockets). Pioneer's thermal data, analyzed and related to other findings, will give a better idea of Jupiter's surface composition. It should also tell the exact ratio of Jupiter's two most-abundant elements, hydrogen and helium, which is considered a key clue to understanding the planet's strange makeup.

Weighing Jupiter. Without even using on-board instruments, Pioneer 10 will weigh Jupiter more accurately than ever before. Tracking data on Earth, computer-processed to reveal the planet's effect on the spacecraft's course, will pinpoint Jupiter's mass—and thus circumscribe more narrowly what its innards could possibly be made of. (The hydrogen-helium ratio, too, should tell something about the composition of its deep interior.)

Because Jupiter appears so much lighter in weight than would be expected from its size, its inside seems bound to be something extraordinary. Many believe it consists largely of metallic hydrogen, a substance that theoretically could be formed from ordinary hydrogen under Jupiter's presumed internal pressure of millions of atmospheres. (Recent U.S. and Soviet attempts have been made to produce metallic hydrogen on Earth, with high explosives, but proof of success is still awaited.)

A four-second burn of Pioneer 10's thrusters recently trimmed its course slightly to assure that it will pass behind Jupiter's orange moon, Io, about the size of our own moon. As it does so it will tell whether Io has an atmosphere, by the effect on Pioneer signals to Earth that would pass through it. The same technique will explore the ionosphere of the Jupiter atmosphere.

Like the Earth, Jupiter has a magnetic field—and a magnetometer on a long mast extending from Pioneer 10 will measure its strength.

Also like the Earth, Jupiter has Van Allen belts of radiation—but believed many times as powerful. They are held responsible for much of the radio noise emitted by Jupiter—which, to radio astronomers, is the noisiest of the planets. Pioneer 10 will sail right through the belts, gathering information about them with a whole array of instruments—principally, a Geiger-tube telescope and a "trapped-radiation telescope."

Will radiation thwart mission? Observers on Earth will have tense moments as Pioneer 10 braves Jupiter's Van Allen belts. Depending on the radiation's unknown intensity, it might imperil the mission by knocking out some if not all of the Pioneer instruments. Designers have taken the threat seriously enough to provide for disconnecting damaged elements from a multiple-sensor instrument, by remote command.

But even if worst came to worst, Pioneer 10 has a backup. Trailing along behind it is a twin—Pioneer 11—built by the same maker and carrying the same instruments. (It also has a magnetometer to measure a more intense magnetic field than Pioneer 10 could, in case Jupiter's is stronger than anticipated.) It was launched last April and will reach Jupiter in 1974. When we know Pioneer 10's fate, there'll still be ample time to alter the course of Pioneer 11 accordingly.

If Van Allen radiation has blitzed Pioneer 10, Pioneer 11 may be taken through a higher, less-damaging trajectory—at the cost of some resolution in pictures and sensor readings.

But if Pioneer 10 comes through with flying colors, Pioneer 11's controllers probably will be emboldened to send it swooping down to a "grazing" flyby only 21,600 miles from Jupiter—and to pictures of greatly enhanced resolution.

As I write this, Pioneer 10 has already scored a space triumph—the first exploration of the Asteroid Belt, which it took seven months to cross. By emerging unscathed, it allayed fears of the threat of this celestial obstacle course—made up of flying chunks of cosmic debris of up to 488-mile diameter—to spacecraft bound for the outer planets.

All we really knew before about the Asteroid Belt was that it included 1776 identified objects of more than the minimum size our most powerful telescopes could detect—about a mile in diameter. These were considered too few and far between to be likely to imperil a spacecraft; the worry was whether the belt might be filled with zillions of smaller particles, down to the size of a grain of sand, that could still damage a craft or its delicate equipment. Now we know that it isn't, and that Pioneer 10's successful crossing wasn't just a lucky chance.

Asteroid Belt no menace. We have the inside story from two devices, included for the purpose, in Pioneer's instrument package. A set of hollow, gas-pressurized panels registered punctures by the smallest particles, and an array of optical telescopes observed particles up to a diameter of about one mm (or 1/25 inch) passing near the spacecraft. (Larger ones, relatively rare, were of less concern.)

What Pioneer 10 reported will rewrite the textbooks. Particles of 1/10 to one mm were only three times as plentiful in the Asteroid Belt as outside it. Smaller particles, contrary to expectations, were *no more* numerous there than elsewhere. Exit that bugaboo!

En route, Pioneer 10 has been making good use of other instruments. One called a plasma analyzer, observing ions and electrons from the sun, is studying this "solar wind" to ranges unexplored before. A cosmic-ray telescope has been reporting data new to science. The Jupiter camera has had an advance workout, mapping "zodiacal light" scattered by interplanetary dust.

Beyond Jupiter. As Pioneer 10 loops around the far side of Jupiter, the mighty gravity of the orbiting planet will accelerate it as if it had fired another rocket stage, to a new speed record of more than 80,000 mph. This "gravity assist" will send it hurtling across the orbits of Saturn, Uranus, Neptune, and Pluto (without, however, coming near any of them)—and clear out of the solar system. On the remote chance that it might ever be sighted and recovered by other-worlders, it bears a gold-anodized aluminum plaque with symbols and pictures to tell them whence it came.

Pioneer 11 may elaborate upon the script for its predecessor. If it does descend to within 21,600 miles of Jupiter, its sharper zip-around course will put it in a trajectory to intercept Saturn in 1980—with its observing gear and radio still in business. Thus, seven years after you read this, a long-forgotten Pioneer 11 might surprise the world with a bonanza of data and pictures of the next big puzzle "out there," the planet Saturn with its unique rings and many moons.

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Popular Science

THE What's New MAGAZINE

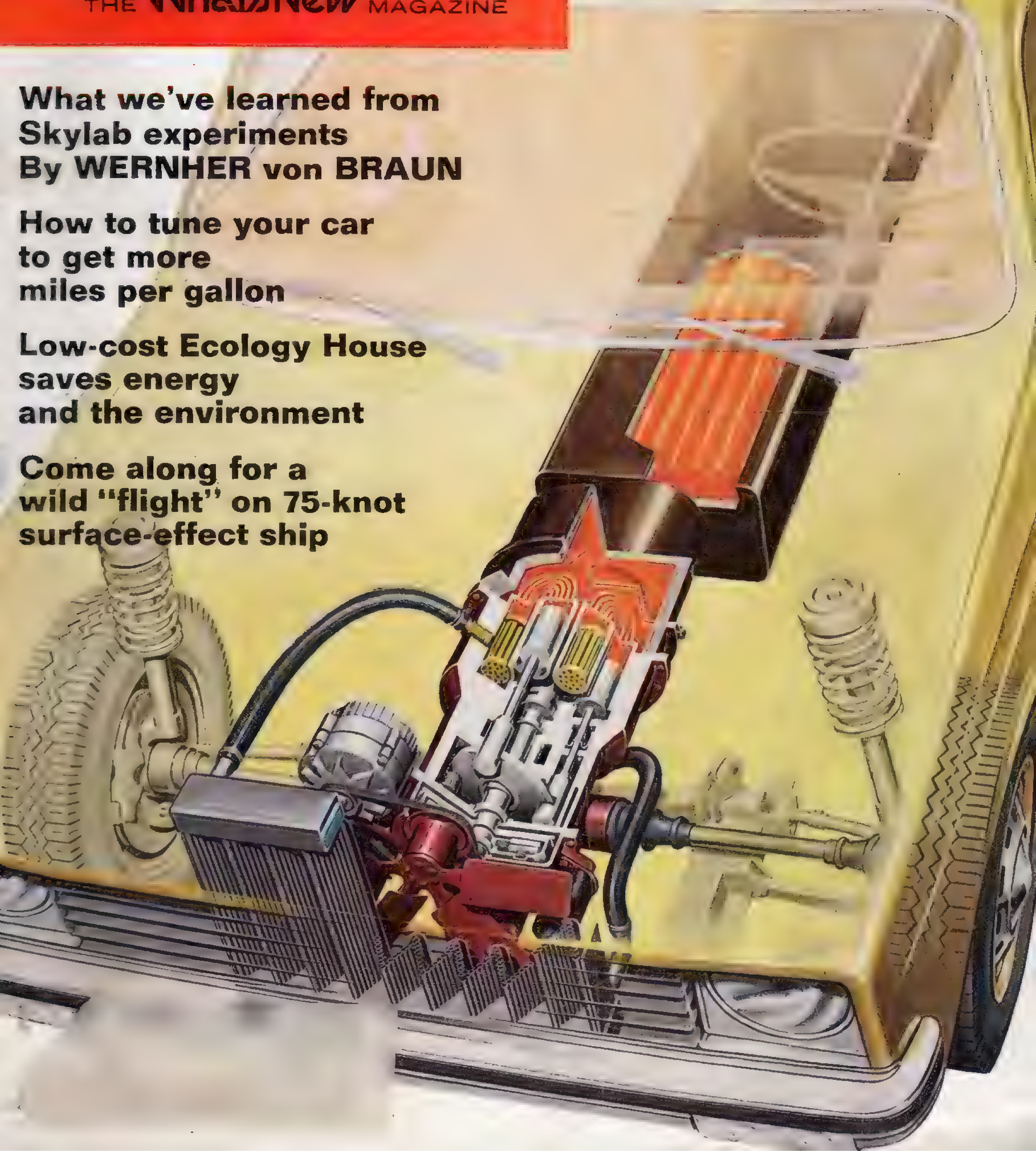
Stored heat powers new pollution-free STIRLING-CYCLE AUTO ENGINE (saves fuel, too)

What we've learned from Skylab experiments By WERNHER von BRAUN

How to tune your car to get more miles per gallon

Low-cost Ecology House saves energy and the environment

Come along for a wild "flight" on 75-knot surface-effect ship



What we've learned from Skylab's

Our $2½-billion space-station project richly paid its way in surprise discoveries and exciting new technology. Here's a fascinating advance glimpse of some highlights of its practical results

They traveled as far as to Mars and back, 70,500,000 miles in all. The three Skylab crews successively set new world records for duration of manned spaceflight, of 28, 59, and 84 days. Most of their total 171 days in orbit, at 270-mile altitude, was spent within their 118-foot-long station—but they spent as much as 41 hours outside it on spacewalks, including sorties for repairs and to retrieve priceless solar telescope films.

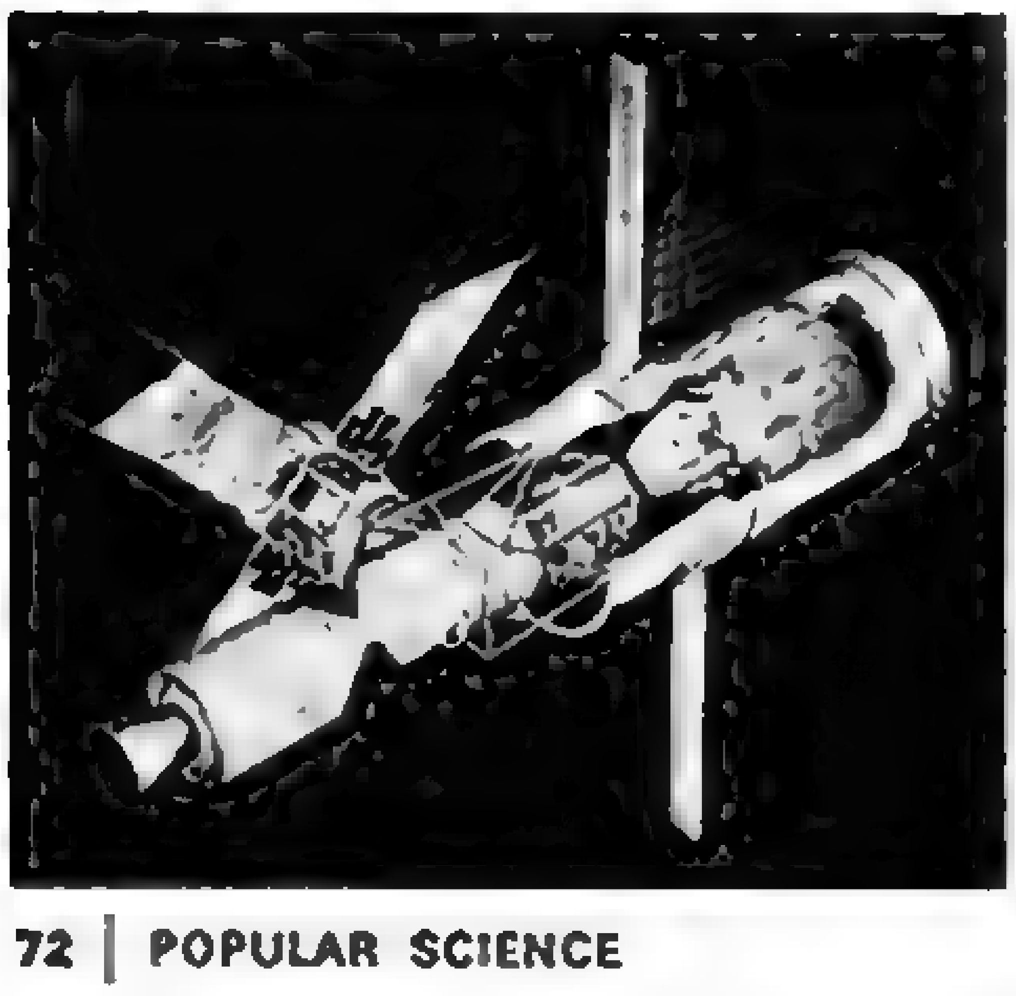
Skylab marked the transition of our manned space program from the *exploration* to the *exploitation* of space, as NASA Administrator James C. Fletcher put it. The 100-ton space station became an orbiting laboratory for more than 800 trail-blazing experiments, in fields including earth-resource surveying, meteorology, oceanography, solar physics, zero-gravity engineering and manufacturing, and life sciences. Besides reports of the findings by logbook entries and recorded voice commentary, the three Skylab crews brought back more than two tons of films, and upward of 50 miles of data-bearing magnetic tape.

It will be years before this wealth of pictures and data can be fully studied and evaluated—but at least a brief, fascinating glimpse of the $2½-billion Skylab project's results can now be given. It was offered last February in the first scientific symposium on lessons learned from Skylab, which I attended in San Francisco. Here are the highlights:

No time limit in zero gravity

Skylab's crews did far more than return the duration record for manned spaceflight to the U.S. and raise it to fantastic new heights (see table). Apparently they've supplied at last the hitherto-unknown answer to a classic space question, "How long can a man safely remain weightless?"—with the headline-worthy reply, "There is no limit!" Although studies of their experience in weightlessness will continue for months, medical experts so far have seen no effects that set *any* bounds to the duration of living in zero gravity.

The explanation appears to be that well-recognized body changes in zero-g (such as a drop in mass of red blood cells, or in calcium content of bones) ultimately slow down and, probably, level off at a plateau where the body is completely and stably adapted to weightlessness. By various current estimates this may take from a month to 50 days; Skylab missions were the first ones long enough to observe it. And on return to earth, the Skylab missions show that complete readaptation to normal gravity follows.



How Skylab actually looked in 270-mile-high orbit is seen above, in photo by last crew at departure. Contrasting preflight NASA drawing (small view below) shows how it was meant to be. In mishap during ascent to orbit, space station lost one solar wing—giving lopsided appearance—and heat-and-meteoroid shield of main section. Astronauts' repairs made it work regardless, saving $2½-billion project. In large photo, patch atop near end is sunshade rigged by second crew, replacing "parasol" first used to make Skylab habitable.

By WERNHER von BRAUN
PS Consulting Editor, Space

pioneering experiments

Skylab's wealth of pictures and data will take years to study fully, says author von Braun—but here he gives an advance glimpse of the momentous findings.

This big news from Skylab transcends purely medical interest because it has intensely practical aspects from a *hardware* standpoint:

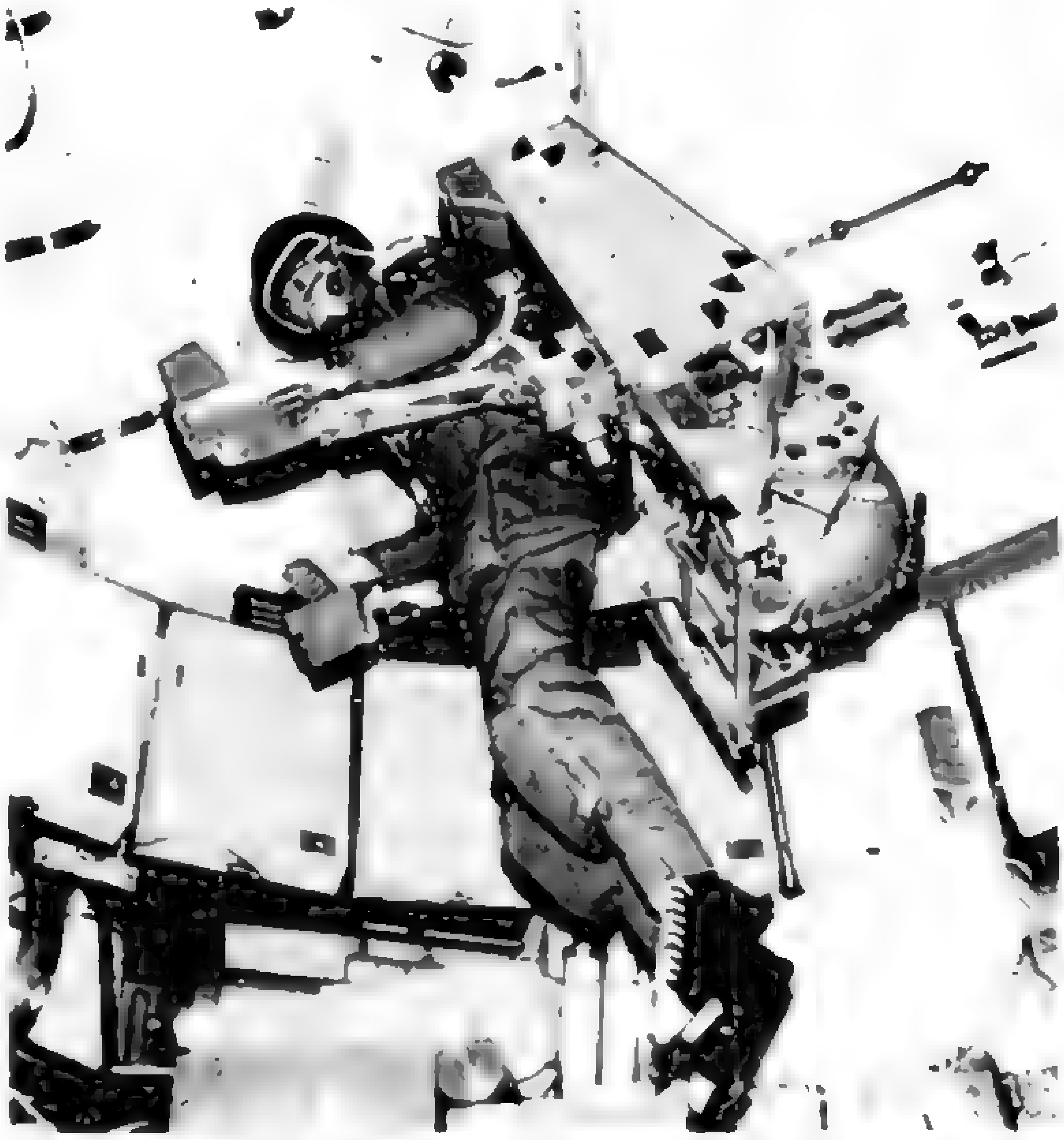
Giant ring-shaped space stations have been envisioned, rotating like a wheel to replace gravity by centrifugal force if necessary. Designing a manned spaceship to go to another planet would become even more complicated, I once pointed out in PS, if a rotating cabin were needed. Now it appears that providing artificial gravity for either a space station or a spaceship can be dispensed with.

Wherever spacecraft go, an all-clear for man's unlimited stay will be a major advantage. One of Skylab's outstanding lessons was the benefit to speed and quality of research of having man in a space laboratory as experimenter, judge, and decision-maker. And his presence permitted many objectives simply unattainable by unmanned spacecraft, however sophisticated, remotely controlled from the ground.

Jet-propelled astronauts

So roomy was Skylab—largest spacecraft ever built—that it made an ideal place for safe indoor trials, in zero gravity, of Astronaut Maneuvering Units that will propel future spacewalkers on their errands with a minimum of time and exertion. Better than words, an accompanying photograph pictures an actual flight trial by the second crew's Pilot, Jack R. Lousma, in the forward end of Skylab's Orbital Workshop section. His backpack-type gear propels him with 14 nitrogen-jet thrusters in any direction or attitude he chooses by manipulating hand grips on two armrests.

NASA expects that such aids will play a major role in making space rescues; inspecting and repairing satellites and manned spacecraft; transferring crews and cargoes; and erecting structures like large space stations (or, possibly, assembling huge craft for interplanetary flights) in orbit. The backpack can be worn either over flight coveralls or over a pressurized space suit, as it would be on excursions into space.



A flight-within-a-flight: Inside Skylab, Pilot Lousma tries out a nitrogen-jet backpack to propel future construction men, repairmen, and rescuers in space.

A pioneering factory in space

Future factories in orbit, manufacturing superproducts with the aid of zero gravity, were described in a PS article of mine five years ago [PS, Dec. '69]. Except for a few limited tests in Soyuz 6 that year, and in homecoming Apollo 14 in 1971, practical space trials of the idea began aboard Skylab with a series of 22 news-making experiments—designed to study the effects of zero gravity on such processes as crystal-growing, and making alloys of materials that won't mix on earth.

Most Skylab trials inserted a solid cartridge of a test substance into a cavity in an electric furnace, where it was radiation-heated to the melting point. With gravity absent, the molten mass formed no puddle, but hovered in the center of the furnace. Its ingredients could then mingle in much less inhibited fashion than on earth, since no gravity-driven forces of convection or sedimentation acted to separate light and heavy elements, and mixing of components

Continued

Long-range earth-terrain camera view of Mobile Bay, Ala., showing load of sediment being carried by rivers into bay and then into Gulf, will aid U.S. Corps of Engineers.

Solar observatory's control console is manned by Science Pilot Gibson. Hand controls trained telescopes on selected areas of sun—and, during last mission, on Comet Kohoutek.

Undaunted by zero gravity, the spider Arabella spins a web—no model of perfection, but demonstrating that animals can cope with a situation never before met by their kind.

of the melt resulted purely from random diffusion.

The hope was that, when the melt was allowed to solidify again under carefully controlled temperature conditions, some materials would form large and nearly perfect crystals—while others would produce alloys that simply could not be made on earth. These expectations were more than borne out.

From the furnace came an indium antimonide crystal of unprecedented smoothness and perfection. Germanium-selenium and germanium-tellurium crystals 10 times as large as those grown in labs on earth, and much more homogeneous, were made by heating past the temperature of vaporization and subsequent cooling.

All of these exotic-sounding materials are semiconductors, which form the heart of modern solid-state electronics. Upon industry's ability to produce larger and more perfect crystals depends the size and performance of transistors, solid-state chips, switching devices, and even rectifiers.

No less successful were attempts to alloy materials that refuse to mix on earth because of gravity. Gold and germanium, and a lead-zinc-antimony mixture, melted and resolidified in zero-g, yielded metallurgical compositions so finely dispersed that elated experimenters called them "space mayonnaise." Such alloys simply cannot be made in laboratories on earth.

World records for duration of manned space flights—from Gemini to Skylab

Year	Mission	Duration[1]	Nationality	Crew[2]
1965	Gemini 7	13 days	U.S.	Borman, Lovell
1970	Soyuz 9	17 days	U.S.S.R.	Nikolayev, Sevastyanov
1971	Salyut space station	23 days	U.S.S.R.	Dobrovolsky, Volkov, Patsayev
1973	First crew, Skylab space station	28 days	U.S.	Conrad, Kerwin, Weitz
1973	Second crew, Skylab space station	59 days	U.S.	Bean, Garriott, Lousma
1973-74	Third crew, Skylab space station	84 days	U.S.	Carr, Gibson, Pogue

NOTES: All of Salyut 1971 crew lost lives from accidental loss of cabin-atmosphere pressure during return to earth in Soyuz 11 spacecraft. Crews of other missions returned safely.

Third Skylab crew's 1973-74 record of 84 days might stand for a decade, in opinion of observers.

[1]Fractions of days omitted. [2]Skylab crews in order: Commander, Science Pilot, Pilot.

Most of our technological prowess is based on the limited number of metal alloys we can use to build our bridges, aircraft, nuclear reactors, and precision instruments. Under gravity, liquid lead and liquid aluminum will not alloy, any more than oil will ordinarily mix with water. But if zero-g can widen our range of available alloys, a new world may open for us.

Some alloys such as niobium-zinc become superconductive, meaning that their electrical resistance drops to zero at the temperature of liquid helium—452° below zero F. Electrons keep right on whirling through a superconductive coil in a magnet, for instance, even after the power cord has been unplugged. Suppose we could produce, in zero gravity, an alloy that is superconductive *at room temperature.* (There is nothing in the book that says this is physically impossible.) We could then convey vast amounts of electric energy with zero loss to a densely populated urban-industrial district from a safely remote nuclear utility.

Maybe one day we would even have automobiles without gas tanks. A multimillion-ampere current whirling through superconductive coils in our car would replace gasoline. The current would be slowly drained in driving, and the coils would be reloaded with electrons by plugging the car into a wall outlet in the garage. Dream stuff? Perhaps—but dreams are the basis of all real advances.

Skylab's down-to-earth view

An Earth Resources Experiment Package (EREP) aboard Skylab included a long-range earth-terrain camera of 18-inch focal length, looking down from a scientific airlock in the Orbital Workshop section; and an array of six matched multispectral cameras of about six-inch focal length, making simultaneous views in light of different colors or wavelengths, at an optical-glass window in Skylab's docking section. There also were optical and radar sensors, reporting data on magnetic tape instead of film.

Surveying the earth systematically from space began in 1972, with TV pictures that our unmanned Earth Resources Technology Satellite has radioed from 560-mile-high orbit. But no TV scanning system could rival Skylab's pinpoint-sharp photos, direct on film, ferried to earth by its returning crews.

From 270 miles up the earth-terrain camera yielded views vividly revealing highways, bridges, and city blocks. A sample photo of Mobile Bay (preceding page) shows their superb resolution.

[*Continued on page 128*]

[Continued from page 74]

Skylab's magnificent earth photos ["Dazzling New Space Images," PS Feb. '74] have already brought surprise discoveries. A view made over eastern Nevada, for instance, alerts prospectors to what may prove a rich new deposit of copper, unknown before.

Other noteworthy Skylab photos will permit mapping Paraguay's 500,000-square-mile "Green Hell" of jungle wilderness, undeveloped because uncharted before; reveal cultural and other changes in remote Central and South American regions to the Inter-American Geodetic Survey; aid a search for oil and gas in Mexico, and for other natural resources in Asia and Australia.

The pictures have such worldwide usefulness because Skylab's orbit, criss-crossing a belt between 50° North and 50° South Latitude, gave it a view of about three-fourths of the earth's surface, containing 80 percent of the world's people and 85 percent of its food-growing areas—including the entire contiguous U.S.

Use of Skylab's veritable atlas of earth photos will not be limited to NASA and five other government agencies participating in the project. All EREP photography is being made available to the public, through the Department of Interior's Earth Resources Observations Systems Data Center, Sioux Falls, S.D. 57198.

Seeing the sun in a new light

A principal part of Skylab was the first manned solar observatory in space, the Apollo Telescope Mount, outwardly marked by its own four windmill-like solar-power vanes. Eight solar telescopes viewed the sun, largely by rays unseen on earth, like ultraviolet light and X rays. Most of the 'scopes made photos on films, of which the most spectacular appeared recently in PS ["Secrets of the Sun," PS May '74]. Other instruments recorded key data on magnetic tape.

But what's really practical, however absorbing to astronomers, about observing the sun? For one big answer, the sun is the only operating thermonuclear reactor, so far, in our whole solar system.

All the sun's blazing energy comes from a thermonuclear or "fusion" reaction such as we hope, one of these days, to harness on earth. A massive U.S. research program aims to apply it for electric power. Any new knowledge that Skylab can bring us of the sun, the shining example that the goal is possible, may help. There is an outside chance that we may have the first small thermonuclear utility by 1985. And by the turn of the century, a major part of our needs may be supplied by thermonuclear energy—virtually inexhaustible, because hydrogen from the vast oceans can provide the fuel necessary.

Spacemen view a comet

While Skylab centered upon practical uses of space, its crews didn't neglect precious opportunities to enrich science's knowledge. Time and again, its cameras zeroed in on promising targets of opportunity—of which the most noteworthy was the Comet Kohoutek, newly discovered in 1973.

It was the first time that a manned observatory had ever had an opportunity to observe a comet from space—and Skylab's third crew made the most of it.

They swung around Skylab's solar telescopes to peer at the comet, as each of their craft's 93-minute trips around the earth brought it into viewing range. On two spacewalks they carried portable cameras outside, including an electronic far-ultraviolet camera, for unobstructed views as the comet looped around the sun.

Skylab observed Kohoutek during its approach to the sun and subsequent recession—from November 25, 1973, to February 1, 1974. Though the dimmer-than-expected comet disappointed its audience on earth, the final Skylab crew enjoyed a rewarding grandstand seat. Unusual colorations, including yellow, gold, red, and blue, led scientists to believe that Comet Kohoutek might be far more exotic chemically than had been supposed. They should soon know—for the Skylab instruments' views, made simultaneously in various parts of the spectrum, produced an unprecedented harvest of cometary data.

Weightless webs, taller men

To the life sciences, Skylab contributed discoveries as novel as these:

• To see what would happen when a spider tried to spin a web in weightlessness, Skylab's second crew took two live spiders named Arabella and Anita up into orbit.

If the spiders had simply given up web-spinning in sheer frustration, it would have been no surprise—and no news. What amazed observers was that within two days, Arabella succeeded in spinning a web in zero gravity—and repeated the feat daily thereafter. So did Anita. Their handiwork in space was hardly up to earthly spiders' standards – the kindest words Science Pilot Garriott could find for Arabella's first try were "a very unusual web"—but Dr. Peter Witt, who raised the pair, was fascinated that they could do as well as they did.

He saw a fundamental lesson that may well extend to all animals, human beings included: Without benefit of book learning or intellectual reasoning, they can cope with situations never before experienced in the history of their kind.

• Skylab's final crew became the first to confirm zero gravity's most dramatic effect on astronauts—they grow taller! Only on space flights as long as the Skylab missions has this strange phenomenon been observed.

The last three crewmen each gained in stature, by amounts ranging from three-quarters of an inch up to 1¾ inches—an effect attributed to removal of normal compression, by gravity, of disks in the spine. This Alice-in-Wonderland result of weightlessness was temporary. After splashdown the astronauts regained their normal earth height within six hours, measurements aboard the recovery carrier *New Orleans* showed.

And after Skylab . . .

So exciting are some of Skylab's accomplishments—the space-manufacturing trials, in particular—that their story is destined "to be continued."

There is talk of pursuing the semiconductor crystal-growing tests in the joint U.S.-Soviet Apollo-Soyuz adventure in 1975. In any case, materials-processing equipment will be built into our new Space Shuttle.

Today, with natural resources scarce and the energy crunch upon us, people expect scientists and technologists once again to pull the rabbit out of the hat and work miracles. It could well be that posterity will say Skylab helped to put the rabbit in the hat. PS

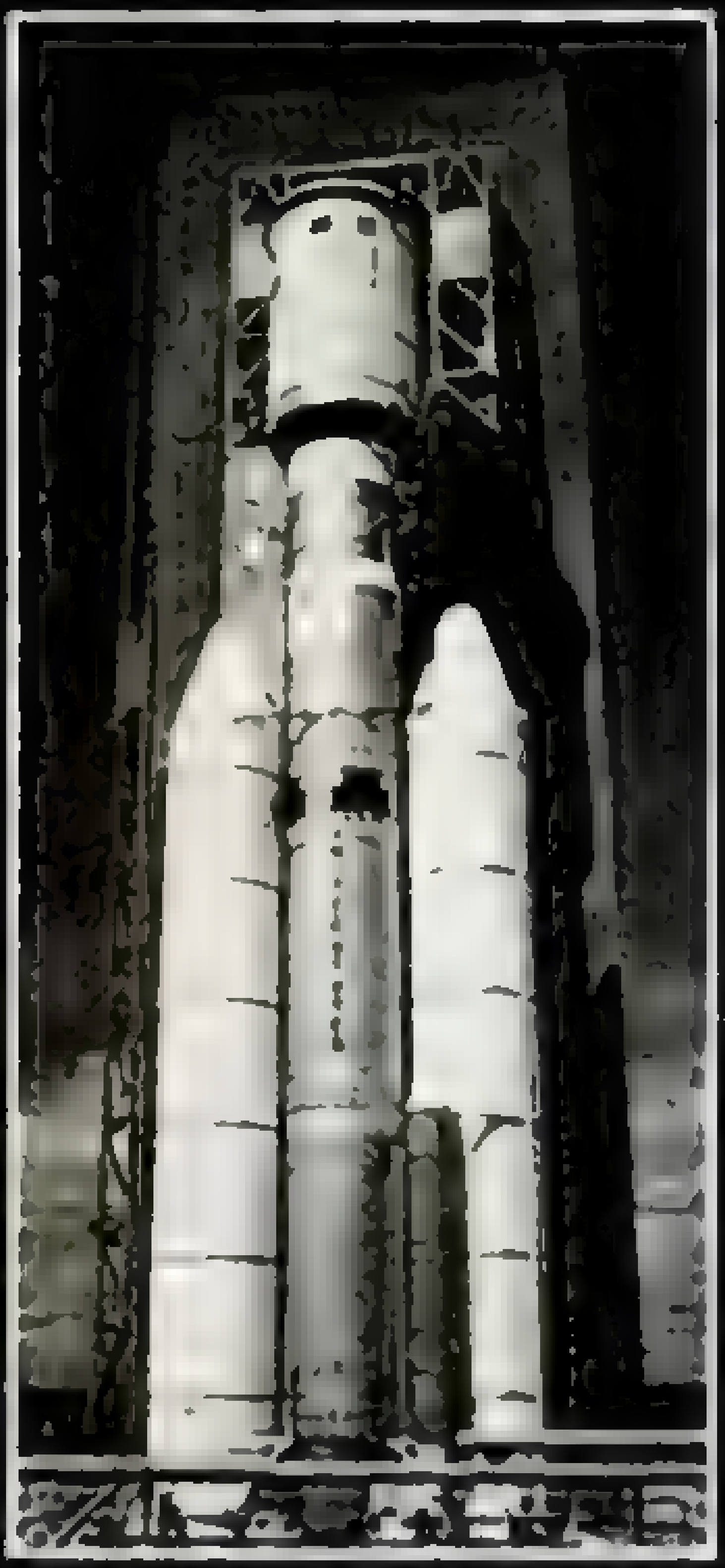
JULY 1974 — 60 CENTS

Popular Science

THE What's New MAGAZINE

Preview of the '75 cars

WIND POWER



Titan 3E, in photo, awaits payload and nose cone for maiden flight. Big drawing previews it boosting a $3^{1}/_{4}$-ton Viking spacecraft folded inside (cutaway portion) on way to Mars.

Record-sized spacecraf

Our

By WERNHER von BRAUN
PS Consulting Editor, Space

ILLUSTRATIONS BY HOWARD KOSLOW

Beginning next year, a new generation of heavyweight interplanetary spacecraft will tell us more than ever before about distant planets of our solar system—and, for the first time, will seek a positive answer to the fascinating question of whether there is life on the planet Mars.

What makes these outsize spacecraft possible is a NASA rocket called the Titan 3E—the biggest interplanetary launch vehicle we ever have had, second in might only to our huge Saturn V moon rocket. Its components are familiar; the combination, brand-new.

Standing almost 160 feet tall overall, when poised for flight, NASA's latest standard launch vehicle harnesses the power of four successive rocket stages. Like the 130-foot-high Atlas-Centaur rocket that has been NASA's standby for interplanetary launches until now, Titan 3E joins two well-proven rocket vehicles into one.

Its lower portion consists of the Air Force's three-stage Titan—of which the current version, long used to launch secret military satellites, is called Titan 3D. Titan 3E's upper and final stage is the high-energy, hydrogen-fueled Centaur, carrying liquefied hydrogen and oxygen as propellants.

A trial flight of Titan 3E last February, although prematurely ended by a malfunction of a small and usually reliable oxygen pump, served its main purpose—to demonstrate that engineering problems of mating the Titan and Centaur rockets had been solved—and NASA announced that Titan 3E was now ready for service.

Before its first interplanetary mission, Titan 3E will flex its muscles this September by launching a Helios spacecraft to observe space phenomena near the sun. While this German-built solar probe

to distant worlds will ride NASA's newest launch vehicle

biggest interplanetary rocket

weighs only a modest 770 pounds, it should achieve a "first": Helios is to come closer to the sun—within some 28 million miles—than any man-made object before. (The present record of about 37 million miles was set recently when Mariner 10 reconnoitered the planet Mercury.) A second Helios, to be launched in 1976, may approach even closer.

Multi-tonners to Mars

The most dramatic demonstration of Titan 3E's might will come next year when it launches the Viking spacecraft to seek life on Mars [PS, Feb. '71].

The Viking carried aboard will be a combination consisting of a Mars orbiter and a lander that will descend from it to the planet's surface. At launch the combined craft will weigh a record 7624 pounds.

The heaviest spacecraft we ever have sent to Mars before was our 2272-pound Mariner 9 Mars orbiter—whose superb pictures of the planet made history in 1971-1972. Mariner 9, like our preceding Mars spacecraft, was launched by Atlas-Centaur. Its weight was within the capacity of that launch vehicle only because of the unusually favorable position of Mars at the time. The Viking, of which Titan 3E will launch a pair during 1975 (and possibly a third in 1979), will be about three and a third times as heavy as Mariner 9.

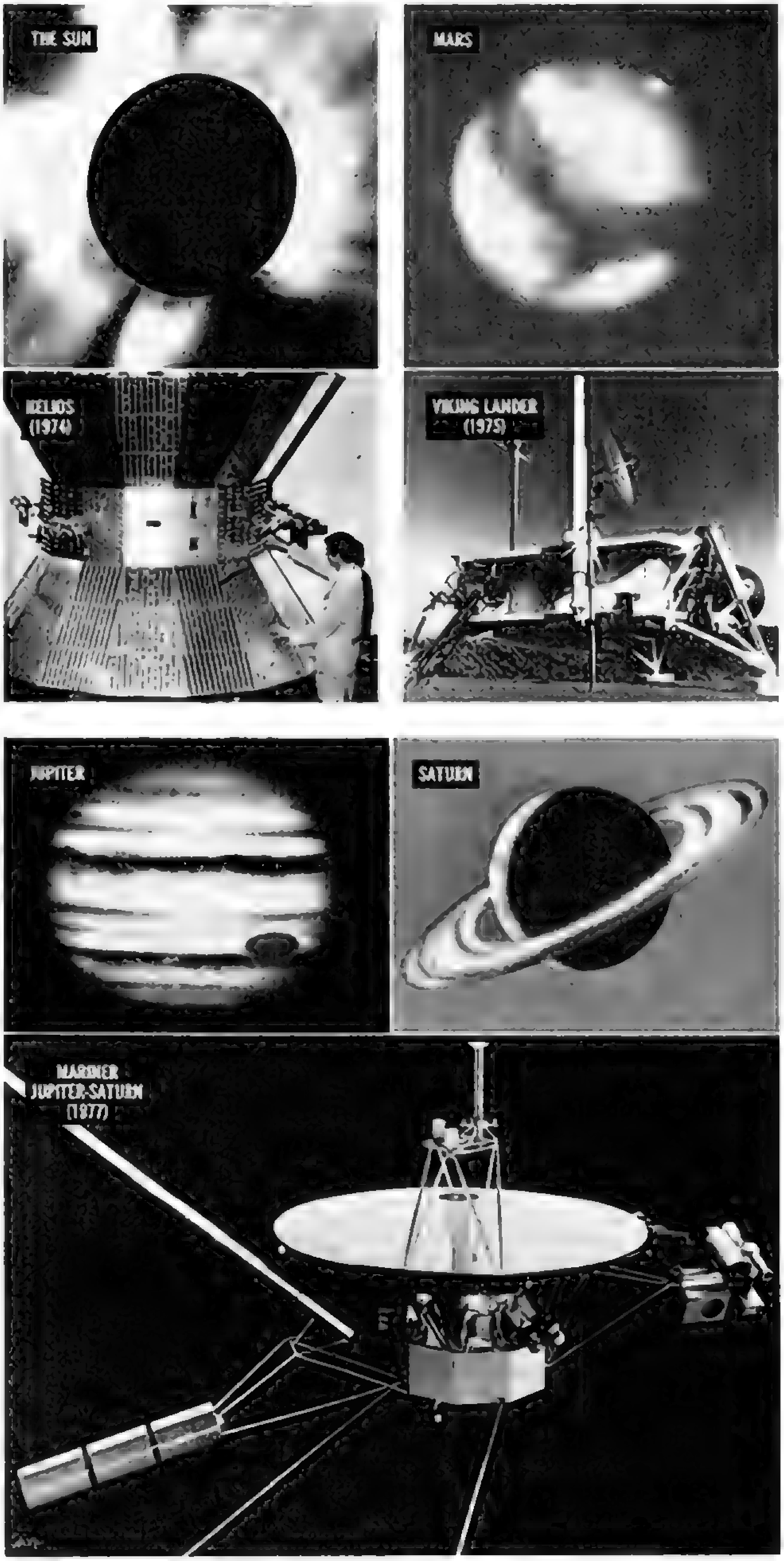
Next—Jupiter and Saturn

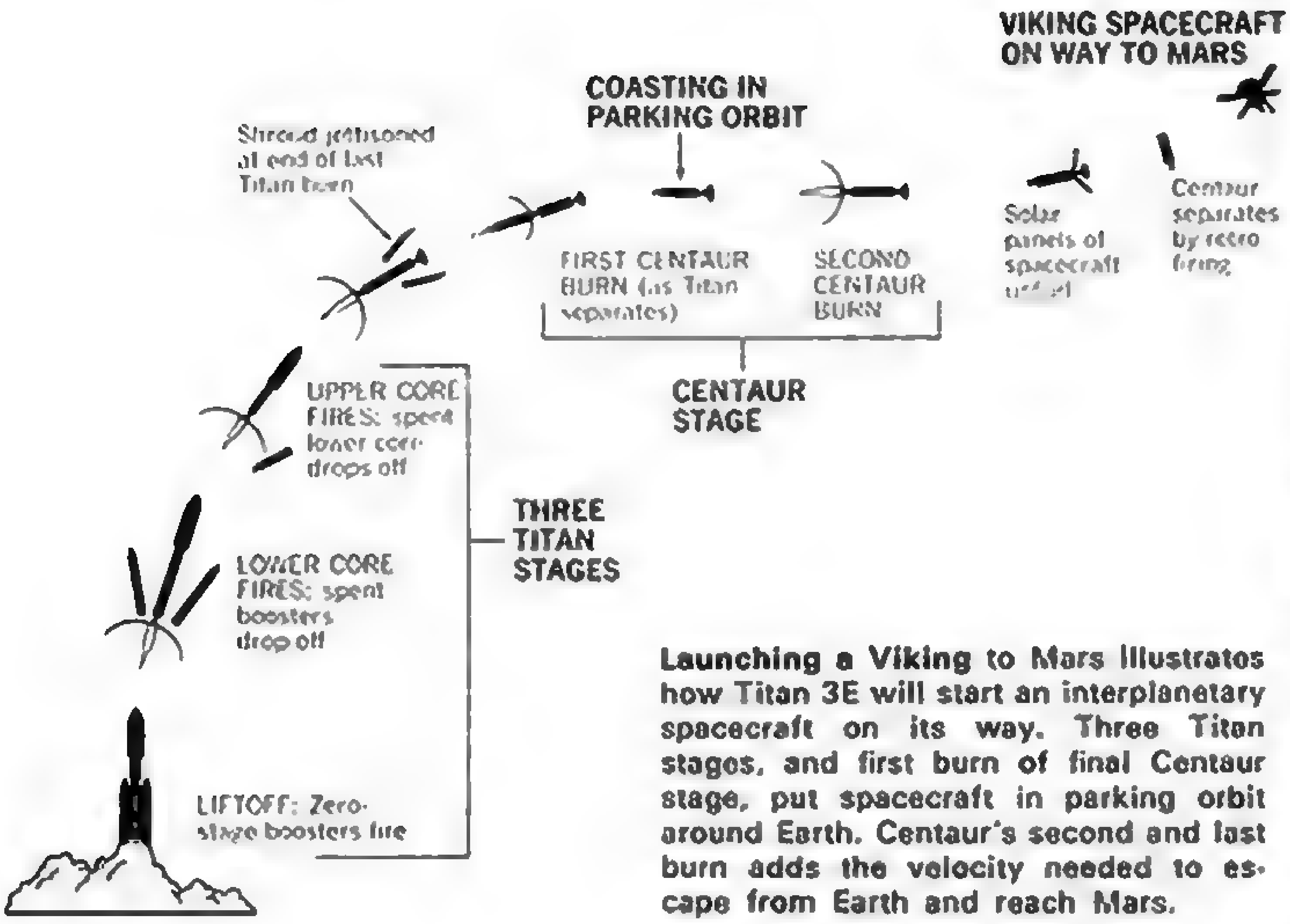
When NASA prepared to launch Pioneer 10 and 11 to Jupiter in 1972 and 1973, it had no standard launch vehicle equal to the task, short of Saturn V. Its more economical and successful solution at that time was to beef up its Atlas-Centaur by adding a solid-fuel third stage.

Even so, the tremendous energy required to reach an outer planet limited the weight of each Pioneer to only 570 pounds [PS, Dec. 1973]. Pioneer 10's striking success was actually a tribute to its designers' wonder-working in miniaturizing instruments and a serviceable though unconventional camera. Its twin, Pioneer 11, will reach Jupiter this December—and the decision has just been made for it to go

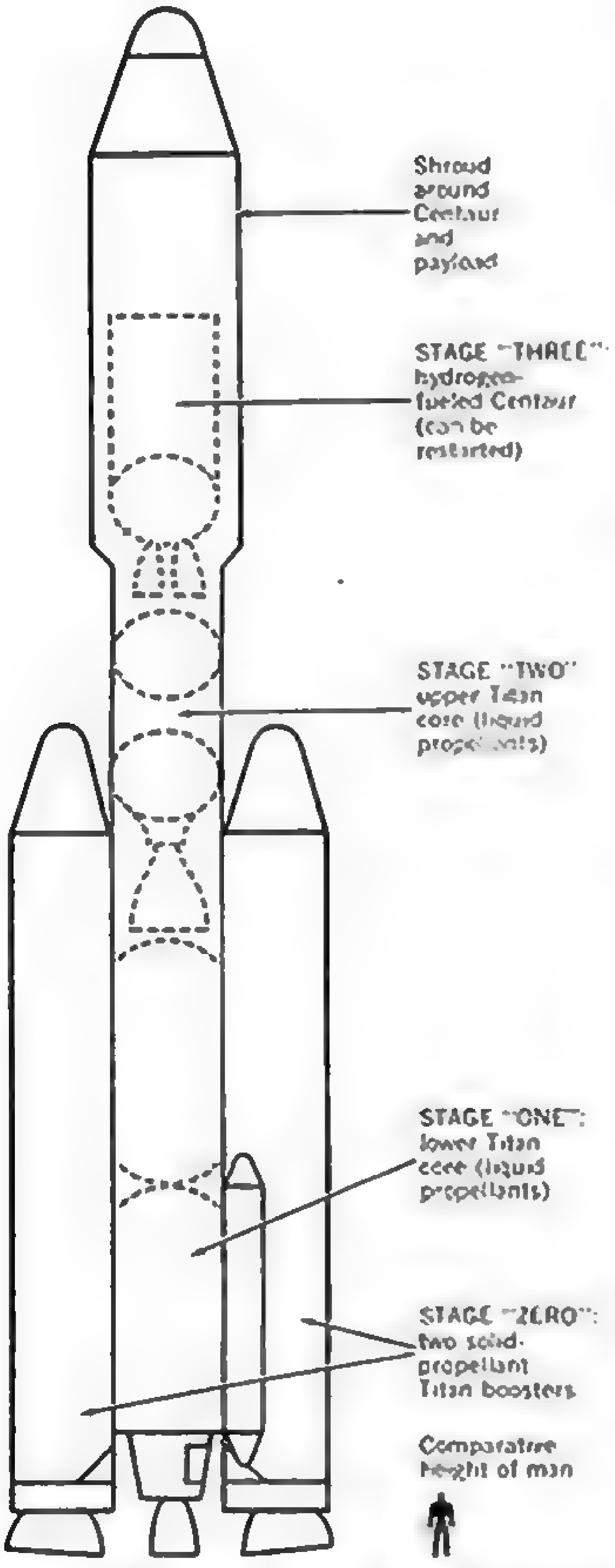
Continued

To these targets, the new interplanetary rocket will launch these spacecraft





Launching a Viking to Mars illustrates how Titan 3E will start an interplanetary spacecraft on its way. Three Titan stages, and first burn of final Centaur stage, put spacecraft in parking orbit around Earth. Centaur's second and last burn adds the velocity needed to escape from Earth and reach Mars.



Titan 3E's four stages are shown in diagram. Reason for odd numbering: Early Titans had two stages, still called "one" and "two" when strap-on boosters were added. Boosters became "zero" stage; Centaur, stage "three."

on to Saturn, with the help of a gravity assist from Jupiter.

Scheduled for 1977, two Mariner spacecraft launched by Titan 3E will each go to both Jupiter and Saturn. The permissible launch weight will be about 1650 pounds for a Mariner—nearly three times the weight of each Pioneer. That means a comparatively luxurious payload allowance for TV cameras and instruments, which seems bound to be reflected in the quality of the Mariners' pictures and data returned to Earth.

Why Titan 3E outperforms Atlas-Centaur, you need be no rocket expert to see. Since the Centaur stage in each is the same, the reason must be the advantage of the Titan over the Atlas in propulsive capacity.

Actually, Titan lifts off with more than four times the thrust of Atlas. It fires two more stages before Centaur takes over, compared with less than one full Atlas stage (the sustainer engine's continued burn after booster cutoff). While Titan 3E is far heavier to launch than Atlas-Centaur, the Titan engines' combined capacity more than makes up for the difference.

That hammerhead shape

Naturally the benefits of mating Titan to Centaur have long been obvious; but, until now, so have been the engineering problems.

Oddly, the one most outwardly conspicuous has proved the least troublesome—the disparity between the diameters of the Titan core and the four-foot-thicker Centaur shroud, giving a peculiar hammerhead shape. Tapering the shroud slightly at the junction (see lower diagram on this page) made the bulge aerodynamically acceptable.

More serious were inherent temperature extremes within the combination—Centaur's supercold propellants and Titan's tepid ones, plus the need to prewarm Centaur's engines, precool Titan's nearby guidance system, and protect delicate payloads. Special insulation helped to make the hot and cold spots compatible.

Teaming Titan's Earth-oriented guidance system with Centaur's for space missions was a final problem successfully overcome.

Now that Titan 3E is operational, it has the prospect of becoming NASA's largest launch vehicle in active use since our two remaining Saturn V's are unassigned and mothballed.

The mighty (and comparatively costly) Saturn V has well fulfilled the specific purpose for which it was designed and built—launching our Apollo astronauts to the moon. In May 1973, our last Saturn V launch (minus a third stage) put the 100-ton Skylab space station into 270-mile-high Earth orbit.

Skylab crews made their subsequent ascents in Apollo spacecraft launched by the smaller Saturn IB—which will also be our launch vehicle for an Apollo rendezvous with the Soviets' Soyuz in 1975. Our Space Shuttle will come along within the next few years.

What else for Titan 3E?

Meanwhile NASA is eyeing a variety of possible tasks for its versatile new Titan 3E:

- It could make an excellent launcher for larger-size communications satellites to come. Instead of today's Intelsat 4's, weighing 1600 pounds apiece, 7000-pounders with far more channels or transmitting power could be launched into 22,300-mile-high synchronous Earth orbit by Titan 3E.
- Besides interplanetary missions definitely planned, it's been proposed to launch Mariner spacecraft with Titan 3E for combined flybys of Jupiter and Uranus.
- By far the most novel application of all, unique in space history, could be a comet chase. Under serious NASA consideration is the possibility of gaining a really close look at a comet by intercepting and flying past it with a spacecraft launched by Titan 3E. It's still a project without a definite NASA commitment, but discussion has gone as far as to pick out a tentative target and date for the chase—the comet Encke in 1980. ■

AUGUST 1974 60 CENTS

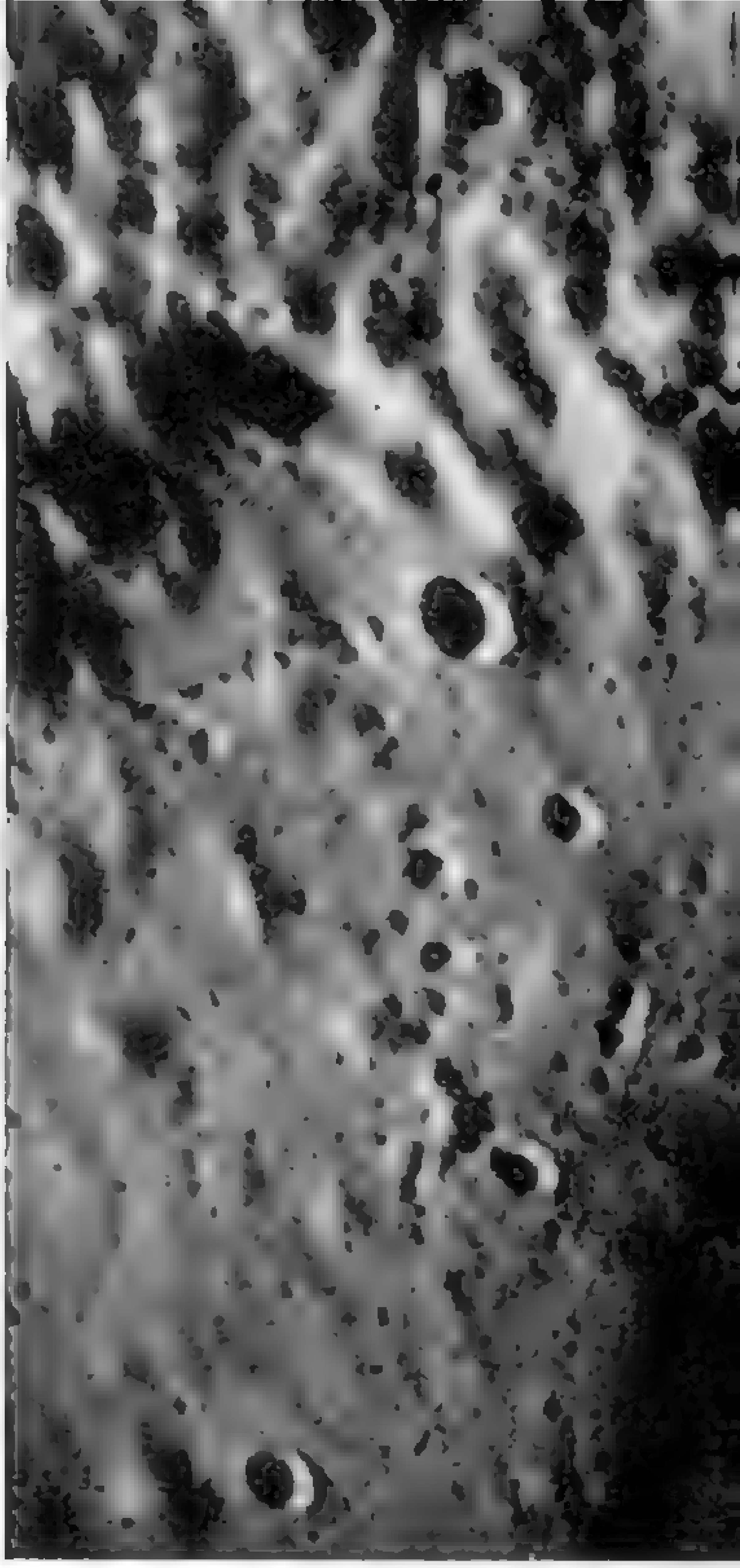
Popular Science

THE What's New MAGAZINE

NUCLEAR FUSION

—our ultimate power source

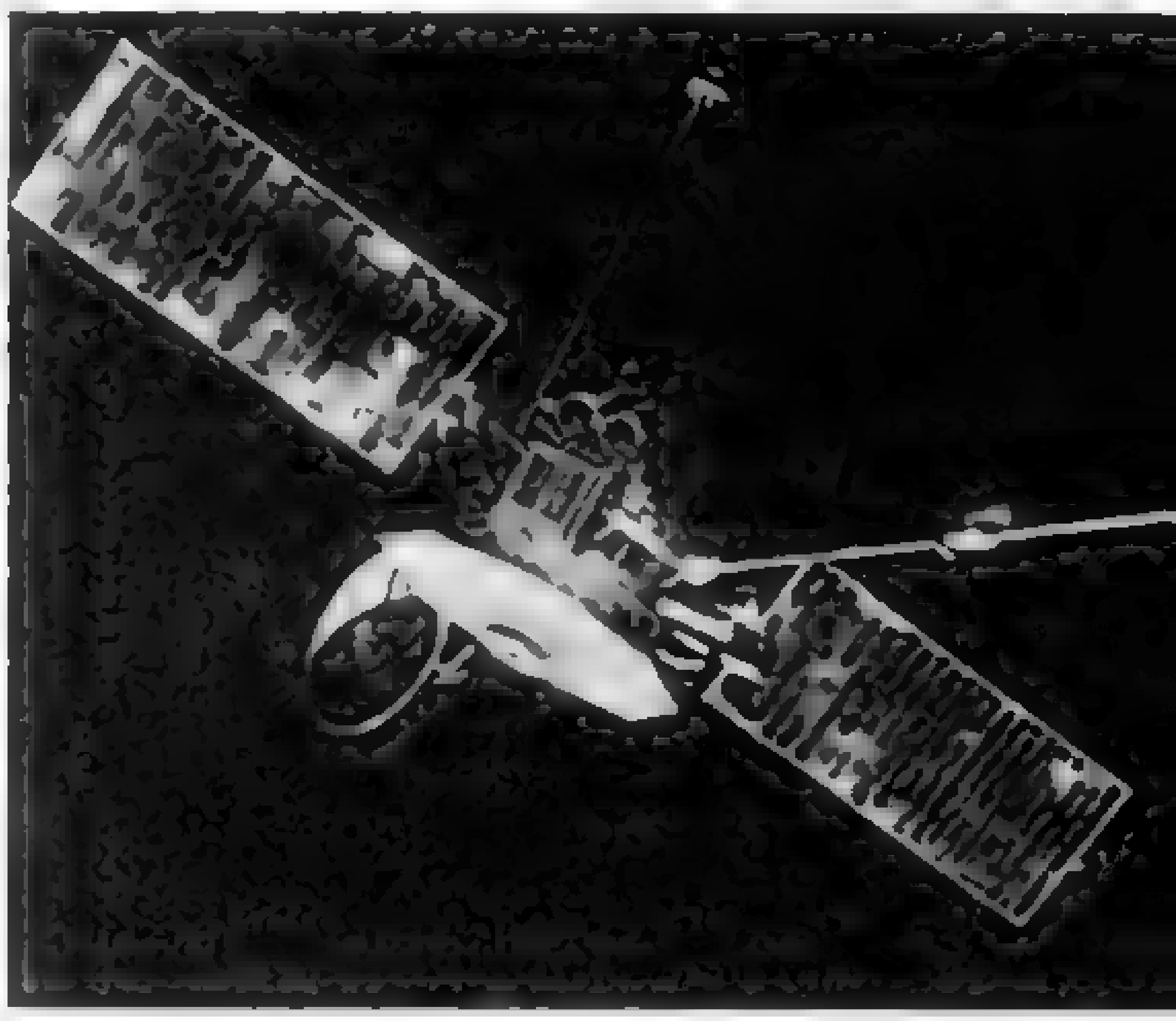
Test report on those GAS-SAVING GADGETS... DO THEY OR DON'T THEY?



Camera gets a breath-taking close-up of

Mariner 10 sends back

The never-



Bug-eyed Mariner 10 needed only two solar-power panels (instead of Mariners' usual four) for flight so near sun. Dish antenna at its bottom sent back signals.

Spectacular overall view of Mercury pictures planet at 124,000-mile range, as Mariner 10 approaches it. Largest crater is nearly 125 miles across. Sun-baked Mercury looks cloudless.

...ratered surface of moonlike Mercury, as Mariner 10 zooms in for a look at details of the terrain.

...wesome views of ...before-seen face of Mercury

By WERNHER von BRAUN / *PS Consulting Editor, Space*

Mariner 10 to Venus and Mercury, our first dual-planet mission and the first to use the "carom-shot" gravity assist technique, is an unqualified success.

Designed to bolster our meager scientific knowledge of the inner planets using ultrahigh-resolution TV cameras and other instruments, Mariner 10 returned a bonanza of high-quality data, including spectacular close-up photos of Venus and Mercury—the first ever. These results, many of them unexpected, will keep planetologists happily bemused for years to come. Here are some of the most striking findings:

- Pictures taken in ultraviolet light show Venus with a streaky, banded atmosphere looking remarkably like the clouds of Jupiter.
- Some Venusian clouds are whirling around the planet at fantastic speeds—about 220 mph.
- Mercury has a battered, pitted crust much like the moon's—anticipated by many investigators. But it also has a weak magnetic field and a thin atmosphere—both surprises.

Built by the Boeing Company for NASA's Jet Propulsion Laboratory, the 1108-pound Mariner 10 was launched by an Atlas-Centaur rocket from Kennedy Space Center in Florida on November 3, 1973. It was aimed to fly by Venus in early February, then use a gravity assist from that planet to aim it on toward Mercury for a March 29 encounter.

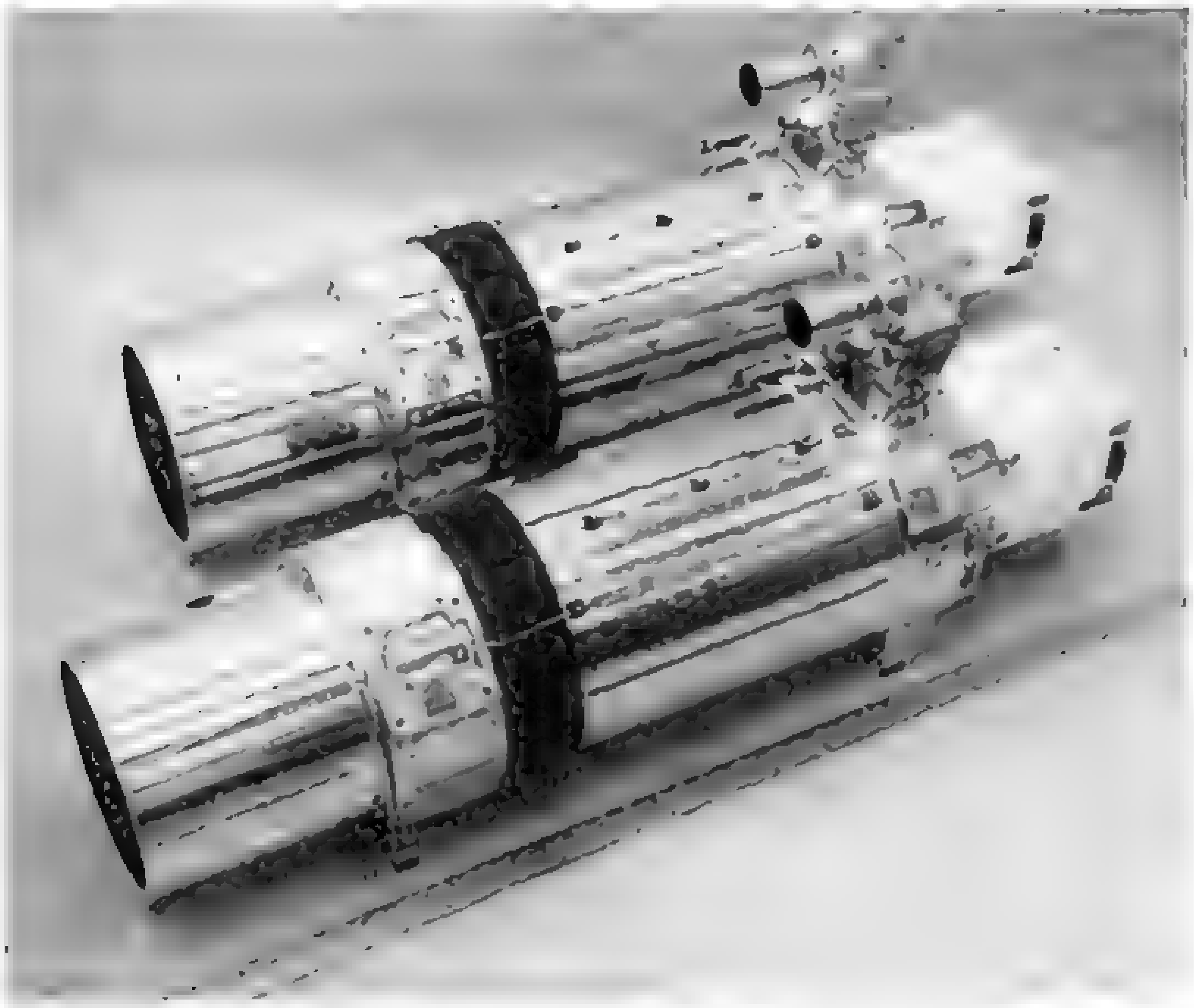
Earlier flybys had made some (nonphotographic) observations of Venus, and the Russians had soft-landed spacecraft on the planet.

Mercury, however, was an almost total enigma, never before visited by a spacecraft, and impossible to see clearly from Earth. Copernicus on his deathbed expressed his regret at never having seen it, and the problems of viewing this smallest and innermost of the planets from Earth remain formidable. It can be seen only shortly before sunrise or shortly after sunset, almost lost in the sun's glare. Moreover, when it is closest to Earth, it is almost directly between us and the sun, so that its dark side faces us.

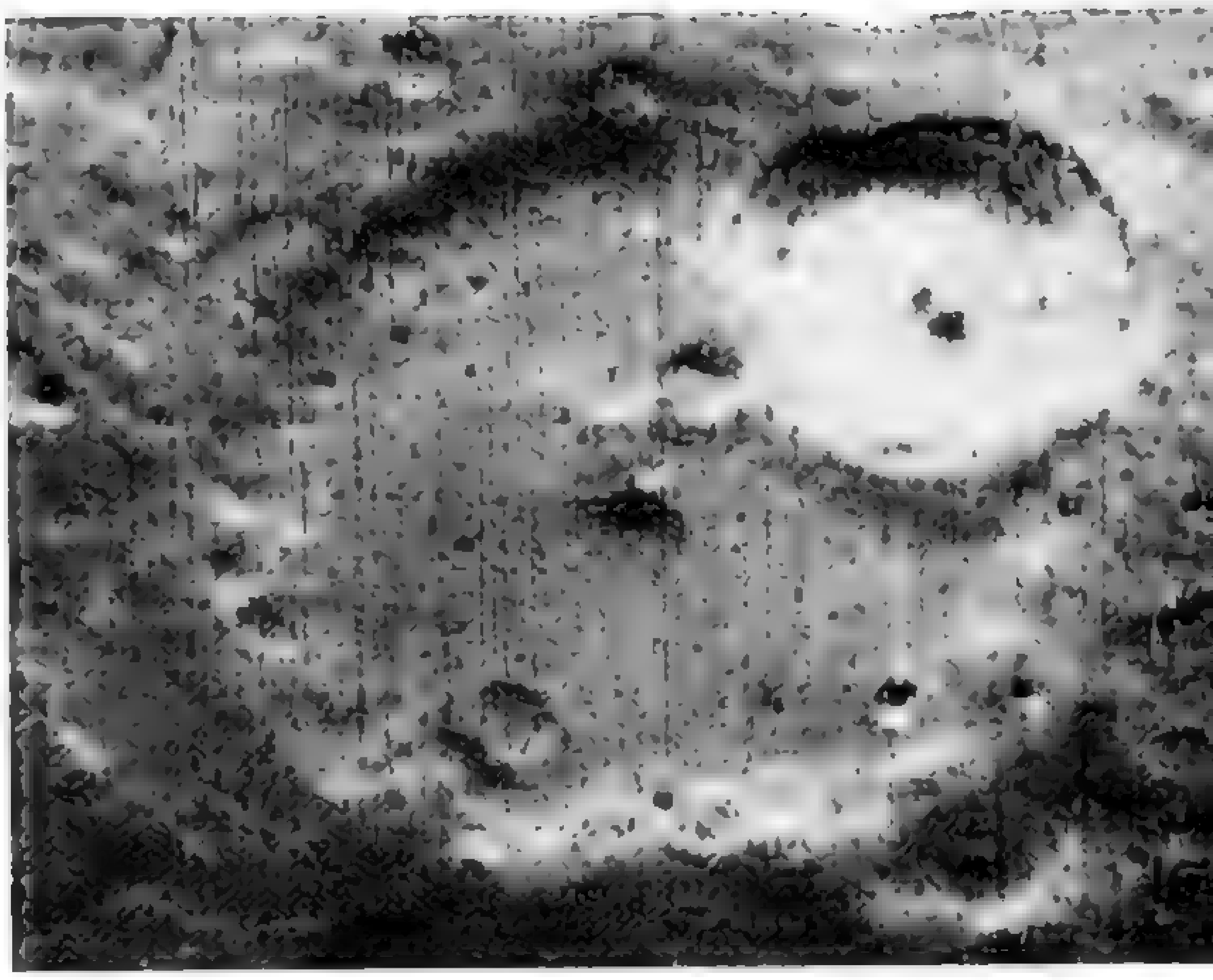
Even with the best Earth-based telescopes, Mercury appears as an almost featureless blob, with perhaps some faint markings—considerably less, in fact, than you can see on the face of the moon with the naked eye any clear night.

By contrast, Mariner 10's twin television cameras have resolved features on Mercury as small as 500 feet across from a close-up distance of about 430 miles. (That's about 5000 times better, by NASA's reckoning, than Earth-based telescopes.) The cameras had a mirror-

Choosing names for features of planet Mercury begins—and ultraviolet photos



Twin telescopic TV cameras of Mariner 10, 36 inches long, gave highest resolution of any NASA ever flew. They could make views by white, blue, yellow, or ultraviolet light.



By right of discovery, U.S. can propose names for Mercury's features. One of first, "Kuiper," for this bright crater on bigger one's rim, honors late member of mission's TV team.

Prize photo of Venus, by ultraviolet light, belies former idea that cloud-hidden planet would look like nothing but a "fuzzy white tennis ball" to a camera. Revealing pattern, above, tells volumes about circulation of Venus' atmosphere.

optics system with a focal length of 1500mm, and they could be changed to wide-angle photography by moving a mirror on a filter wheel to a position in the optical path of an auxiliary system.

According to Dr. Bruce C. Murray, team leader of the television experiment, these are the highest-resolution television cameras yet flown by NASA on any mission, better even than those used in the Lunar Orbiter spacecraft, which mapped the moon in preparation for the Apollo landings.

For a while after the launch of Mariner 10, scientists were very worried—the heaters designed to maintain correct camera temperature failed. But the potentially fatal problem was overcome by leaving the vidicon tubes on all the time.

Battered, desolate, pitted

The results, in thousands of pictures returned to Earth, were remarkable. Across some 93-million miles of space, Mariner 10's twin cameras sent Earth the first, awesome views of the never-before-seen face of Mercury. They revealed a battered and desolate planet with a surface not dissimilar to our moon's, with a variety of impact craters, valleys, and lava-flow regions.

These first and only pictures, incidentally, give the United States the exclusive right to name features on Mercury, subject to formal approval by the International Astronomical Union. Thus, NASA scientists have proposed naming a prominent, 25-mile-wide bright crater in the northern hemisphere after

bare secrets of the atmosphere of cloud-hidden Venus

Dr. Gerard P. Kuiper, a planetary expert and member of the Mariner 10 Television Team who died before the craft reached Venus.

Another feature on Mercury, an 800-mile-wide depression that seems to be a lava-flooded basin, has been dubbed "Caloris" after the Latin word for heat. It may be one of hottest places on the planet, and thus in the solar system. Mariner 10's infrared radiometer recorded temperatures ranging from 370°F on the day side to −280° on the night side at local midnight. Calculations indicate that the extremes, at various times and places, may range from −300°F to 940°F, more than hot enough to melt lead.

These temperature extremes are fostered by a number of conditions, including Mercury's lopsided orbit (from 29 million miles to 43 million miles from the sun) and its very long solar day. Mercury rotates once about its axis in 58.6 Earth days. Combined with its motion around the sun (one revolution in 88 days) this gives a solar day 176 Earth-days long.

The appearance of craters and some other moon-like features did not surprise many planetologists. Radar observations of the planet made with JPL's 210-foot-diameter antenna at Goldstone, Calif., announced early this year, predicted hills and valleys, and the possibility of circular craters.

But most scientists did not expect to find any magnetic field surrounding Mercury. Surprisingly, Mariner 10's magnetometers found a field about one percent that of the Earth's, but considerably higher than anything observed around the moon, Mars, or Venus.

This means that for all their surface similarities, the interiors of the moon and Mercury must be quite different. In fact, Mercury's high density—about equal to Earth's and about half the moon's—makes it likely that it has a large core with a high iron content. Obviously, the lighter silica-based crust floated to the surface while the young planet was molten. The crust solidified and was subsequently cratered by the impacts of orbiting debris attracted by the gravitational field of the new planet.

As Dr. Murray reported to the American Geophysical Union recently, "It's like the moon on the outside but it may well be like the Earth on the inside. For that reason it's unique in the solar system."

Another surprise came when the spacecraft's ultraviolet sensors detected a very thin atmosphere of helium and perhaps other inert gases. This is a puzzle, because Mercury's weak gravitational field should theoretically have allowed light gases such as helium to escape into space long ago. Scientists speculate that the planet's crust may contain beds of radioactive uranium and thorium, whose helium decay products might be continuously replenishing a constantly vanishing atmosphere.

Venus observed

Ironically, when we first started sending spacecraft to Venus in the sixties, we didn't even bother to equip them with cameras, because we "knew" all they would record was something like a fuzzy white tennis ball. The remarkable photo of Venus you see here, made with an ultraviolet filter over the TV cameras, shows what may be the clue to weather on Venus- a circulating pattern of clouds, believed by some experts to be droplets of water and sulfuric acid.

At the top of the dense cloud layer, revealed by Mariner 10's radio instruments to be about 33 miles above the surface, the density of the atmosphere (composed primarily of carbon dioxide with some hydrogen) is about the same as that encountered by a jet flying at 30,000 feet on Earth. But at the surface, the pressure is about that inside a welder's oxygen cylinder.

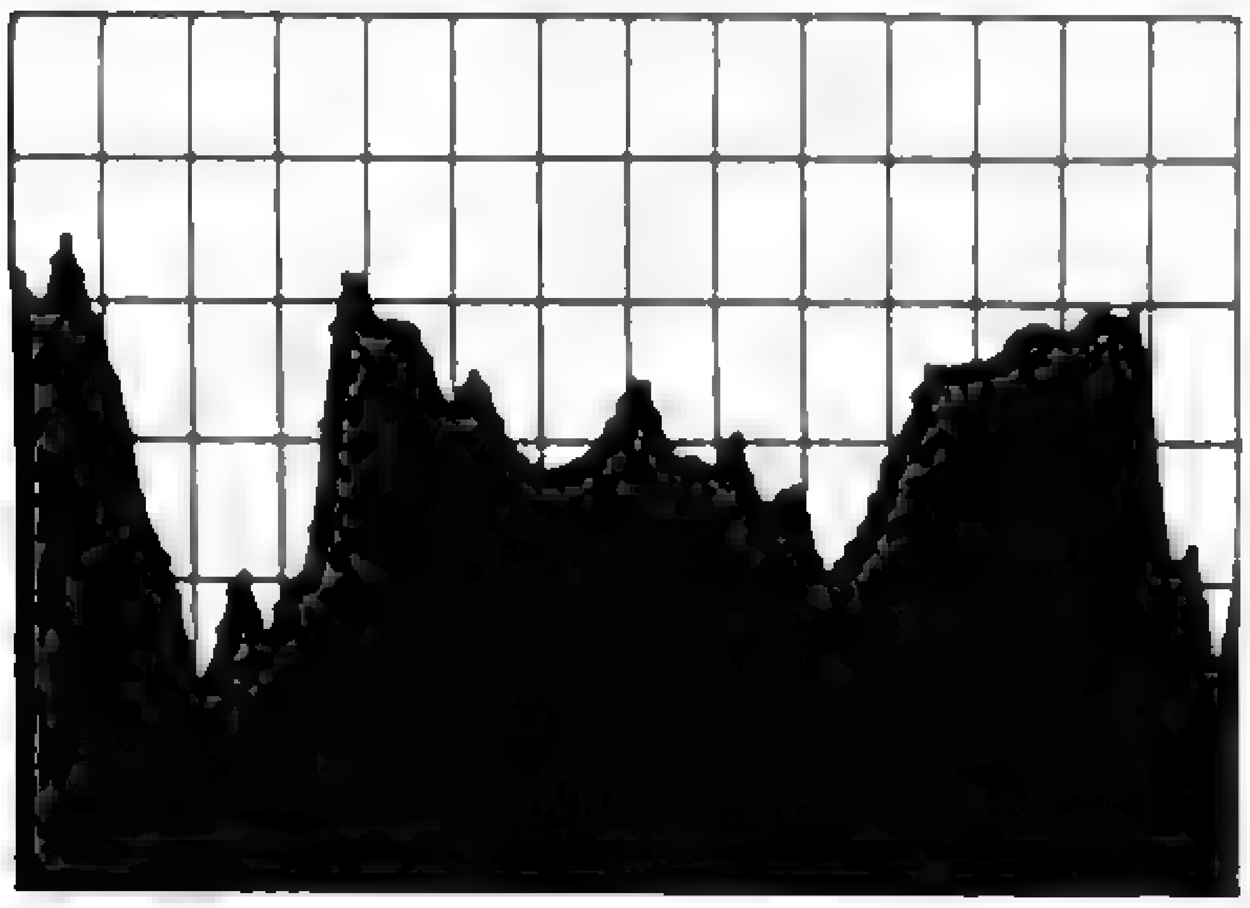
Pictures taken of the atmosphere at 24-hour intervals show that the clouds are moving at phenomenal speeds for as slow-spinning a planet as Venus. Near the equator they are a little faster than jet stream velocities on Earth—about 220 mph. That gives the atmosphere a rotational period of four days, more than 50 times faster than Venus' rotational period of 243 Earth days.

Delighted meteorologists point out that the entire Venusian cloud circulation follows the so-called "Hadley pattern," named for the British scientist George Hadley. In 1735, Hadley theorized that such a planet-wide atmospheric circulation pattern should exist on Earth as a result of solar heating and the planet's rotation.

Mariner 10's successes may not be at an end. On September 21, as it orbits the sun, the craft will again approach Mercury. If all systems are operating properly then, it will either pass Mercury's bright side and photograph its south pole, or swing closer in on the dark side to investigate the planet's mysterious magnetic field.

First two-planet mission began with flyby of Venus. Gravity assist from tug of that orbiting planet headed Mariner 10 on the right course for Mercury.

Radar studies gave an inkling, in advance, of what surface of planet Mercury might look like



First hint of Mercury's appearance, shortly before Mariner 10 got there, came from radar profiles of surface elevations like the sample at left. They were made by scanning the planet's surface with 210-foot antenna, right, at Goldstone, Calif.—which later helped to track Mariner 10. Profiles revealed hills and valleys—but couldn't tell for sure whether depressions were craters. Mariner 10's pictures showed they were.

NOVEMBER 1974 60 CENTS

Popular Science

THE WHAT'S NEW MAGAZINE

Geothermal energy— how science is solving its strange problems

PS guide to buying an imported car

Emergency power for your home

Reusable

SPACE SHUTTLE

flies b

lands

Spectacular launch of Space Shuttle, with Orbiter and booster engines all firing, is visualized by Rockwell International artist. Twin boosters flank the Orbiter's huge external fuel tank.

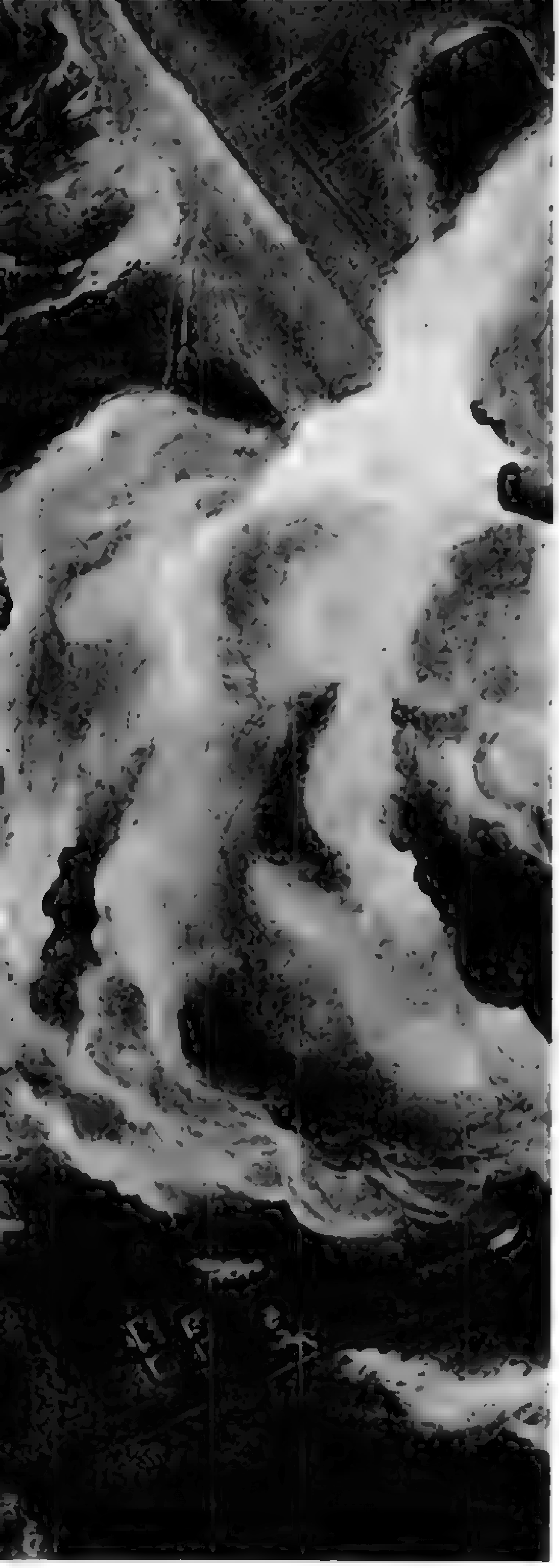
Shuttle puts payloads in orbit 115 miles up—like earth-survey satellite, on manipulator arm, above.

Full-scale Orbiter mockup is shown with doors of great cargo bay open. Manned craft compares in size with that of a DC-9 jetliner.

Reusable

space shuttle

...our biggest bargain in out-of-this-world research



NASA is developing a vehicle that takes off like a rocket, moves into orbit like a spaceship, and returns to earth by landing like an airplane. The Shuttles will be our "railroad" into space in the 1980's

By WERNHER von BRAUN
PS Consulting Editor, Space

If you think our space program is rapidly going out of style, you are wrong. And if you believe that after the spectacular successes of Apollo and Skylab, U.S. space flights will henceforth be limited to unmanned activities, you are wrong again.

Starting in 1979, a new concept in the U.S. space program should drastically reduce the cost of space operations. For the following 12 years, from special launch sites at Cape Canaveral's Kennedy Space Center and Vandenberg AFB in California, manned *reusable* spacecraft will be rocketed into earth orbit.

During that period, some 725 launches, averaging about one a week, are expected. Bus-size payloads weighing up to 65,000 pounds—including weather, communication, earth-resource, military, pollution-control, scientific, and navigation equipment—can be carried into orbit by the Space-Shuttle craft now being developed for NASA by Rockwell International. If the payload is an unmanned satellite, the shuttle will return at once. If manned experiments are involved, the four-man flight crew and up to six passengers may stay in orbit up to a month. The 83-ton, delta-winged vehicle is designed to survive scorching reentries through the atmosphere, landing like an airplane on a runway.

After landing, Shuttle craft will quickly be readied for another mission. Each vehicle can be orbited 100 or more times. This reusable aspect of the Shuttle program lowers the cost per flight to $10.5 million. Orbital transportation cost for each pound of orbital payload will be about $160, compared to $500-$1000 with conventional expendable rockets.

The Space-Shuttle program will include three basic types of missions for government agencies and universities, foreign countries, and commercial organizations:

- Manned scientific or earth-related application missions using a modularized spacelab that remains with the Orbiter.
- Transporting unmanned or man-tended spacecraft to low orbit, revisiting them for modifications.
- Tug missions for higher orbits and unmanned lunar and planetary missions. The tug, an extra-propulsion unit, will be carried with the payload in the Shuttle's cargo bay.

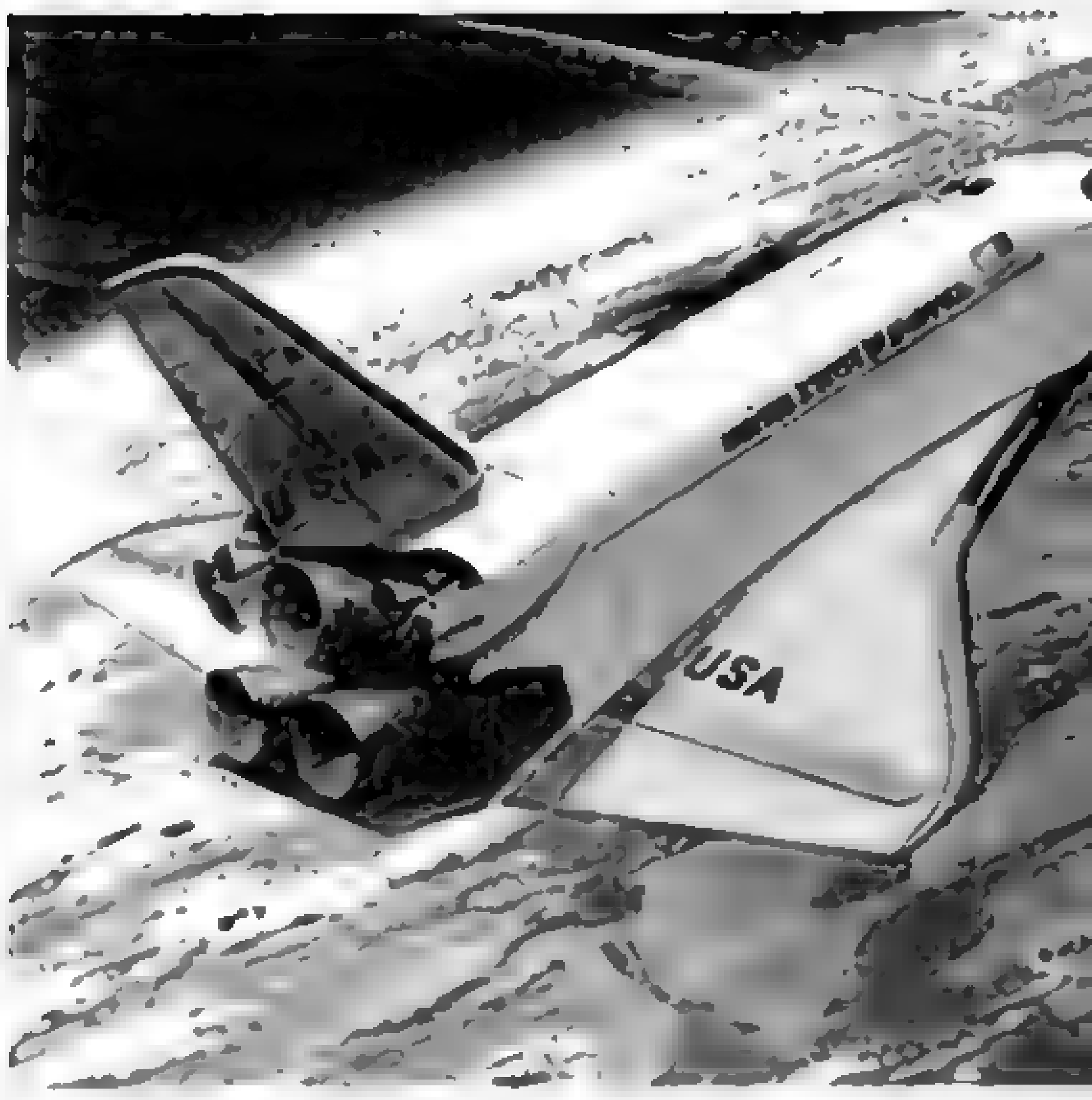
Preparing a launch

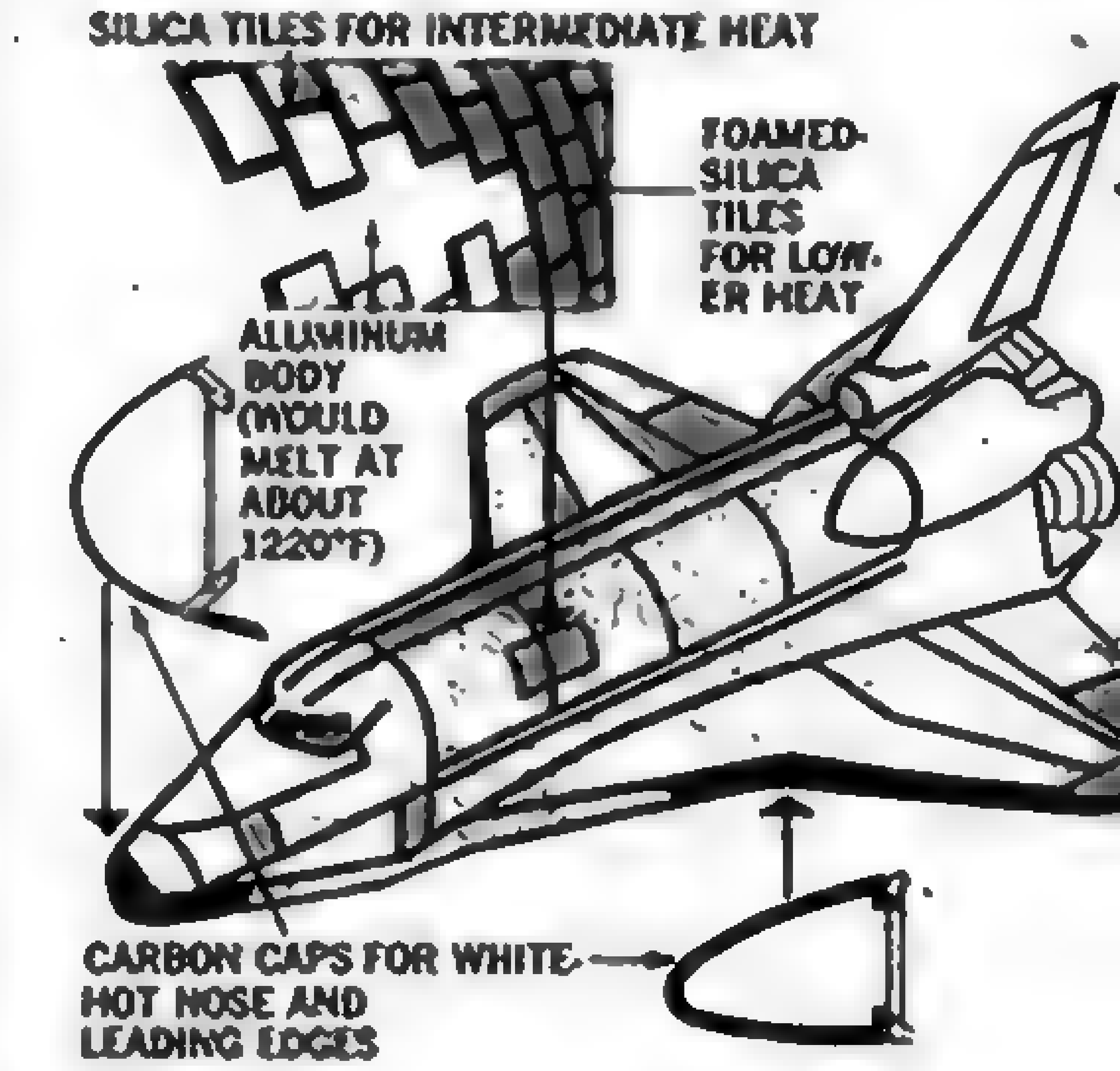
Prior to launch, the payload will be loaded in the cavernous cargo bay in the center of the Orbiter's body. The Orbiter is a DC-9-size, airplane-like vehicle with a 78-foot double-delta wingspan. The payload bay accommodates loads up to 60 feet long and 15 feet in diameter.

The Orbiter has three 375,000-

Continued

Author von Braun tries out copilot's seat in mockup of Shuttle's Orbiter.





Craft defies reentry heat

Most dramatic feature of Shuttle is its ability to emerge unscathed from repeated exposure to fierce heat of reentry—simulated above, with model of first stage of an early, developmental design, in arc-jet facility at NASA's Ames Research Center, Moffett Field, Calif. New heat-defying materials replace expendable ablative ones to cover aluminum Orbiter—"carbon-carbon" caps over white-hot nose and wings' leading edges, and silica tiles over rest (diagram, lower right). At reentry, tile-sheathed craft pitches nose-up (upper right) to limit temperatures at hottest spots, and does a "belly-whopper" into atmosphere.

pound-thrust Rocketdyne engines, but the liquid-hydrogen/liquid-oxygen they consume is not stored in the vehicle. Instead, propellants are carried in a huge external tank—27 feet in diameter and 155 feet long. The Orbiter rides this tank piggyback into space, until, just before orbital altitude, the tank is jettisoned. Also, for the first stage of the launch, two solid-fuel rocket boosters of 2½-million pounds thrust each are side-strapped to the Orbiter's fuel tank.

A simulated mission

Here is what a typical low-orbit flight of the Space Shuttle will be like:

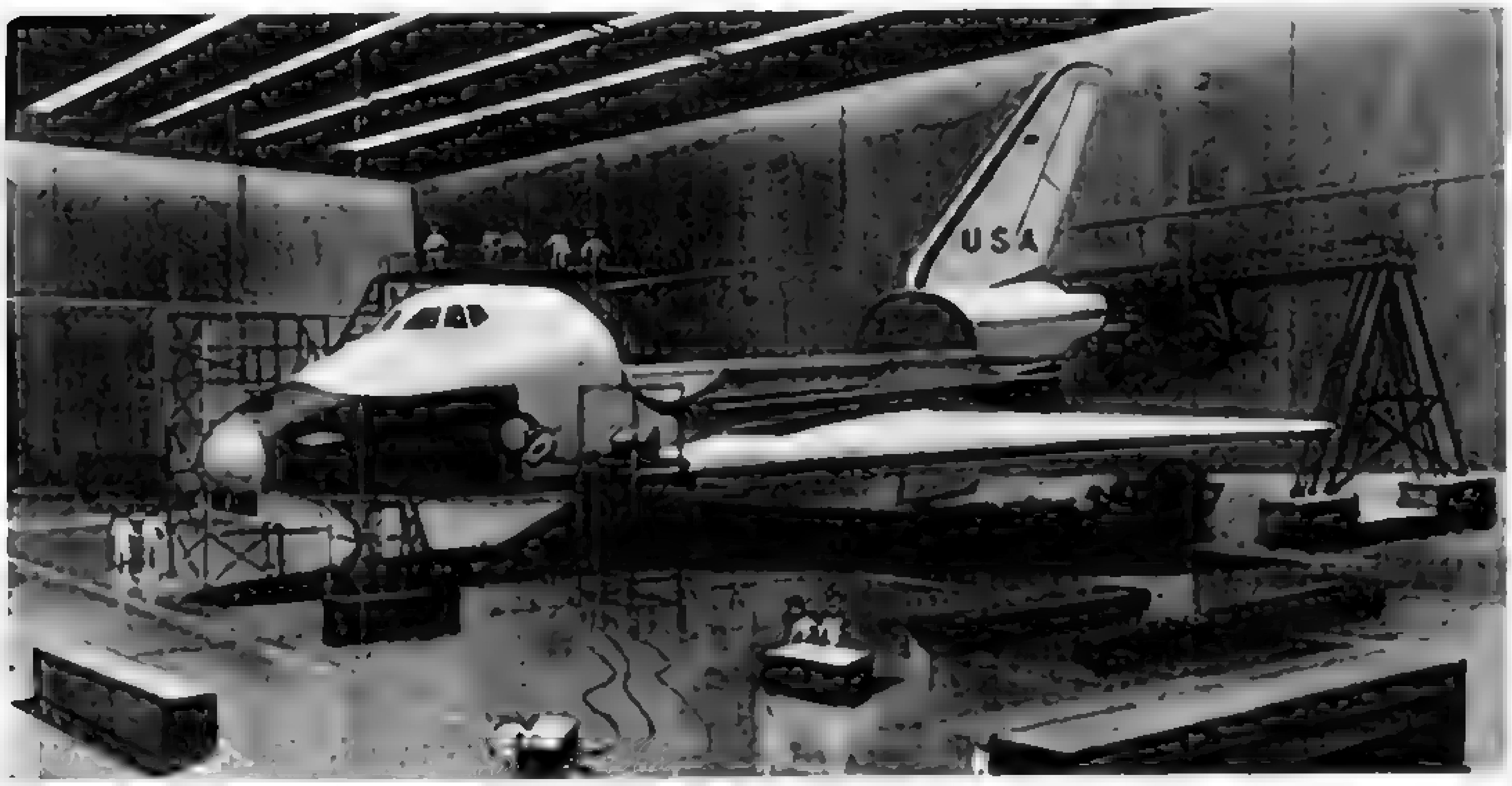
Before the countdown begins, the entire vehicle, 181 feet long and weighing 4.1 million pounds, is moved from a protective hangar to the launch pad on a treaded crawler transport.

The four flight crew members, commander, pilot, mission and payload specialists, are seated on tiltable couches in the upper flight deck. A lower deck has seats for six passengers, sleeping and eating quarters, sanitary facilities, and an assortment of electronics equipment. (The Shuttle will be the first space craft to have facilities for women, since they will no longer be excluded from space flights, according to NASA.) During the flight, passengers and crew experience relatively mild acceleration forces limited to three g's. Acceleration and deceleration forces exceeded six g's during Apollo missions, but the Shuttle is specifically designed to carry passengers who have not undergone rigorous astronaut training.

Liftoff occurs with the simultaneous thrust of the three main engines and two solid-fuel booster rockets. Aerodynamic controls, used later for reentry, are locked, and the vehicle is guided by changing the thrust angle of all five rockets. At an altitude of 27 miles and a velocity of 3210 mph, the solid boosters burn out. The casings are jettisoned and parachuted into the ocean for recovery and reloading.

Meanwhile, the Orbiter's three main engines push it ahead. As the vehicle ascends into the vacuum of outer space, each engine can deliver 470,000 pounds of thrust. At a velocity of 17,600 mph, while moving almost horizontally at about 115 miles up, the main engines are shut off and the external tank is jettisoned. At this suborbital speed, the tank will reenter the atmosphere and burn up like a shooting star.

At this point, two 6000-pound-thrust engines for the Orbital Maneuvering System (OMS) provide the power burst required for a stable orbit. The OMS engines are attached to either side of the Orbiter's rear fuselage. Additionally, the vehicle's Reaction Control System (RCS) provides forty 900-pound-thrust rockets and six 25-pound-thrust vernier rockets for altitude control in orbit and during the early reentry phases. With a full 65,000-pound payload, a due-east orbit of about 240 miles is possible. Replacing payload weight with extra propellants for the OMS en-



Back to earth at 215 mph

Safely past reentry, pilot heads for a more-than-200-mph touchdown on runway, top view—and lowers wheels (dotted lines) just before reaching it.

After landing, craft will be towed immediately to special hangar for servicing, as below, to prepare it for another mission. Quick turnaround aims to have each of Shuttle fleet ready to fly again within two weeks of its return from space.

gines permits higher orbit missions.

Once in orbit, the commander and pilot leave their forward-facing seats and move to control stations that face the rear. The pilot opens the payload doors while the commander maintains the Orbiter's attitude. Riding behind the pilot is the mission specialist, who now swivels his couch to a nearby panel and monitors critical payload services—electrical power, cooling, fluids—the Orbiter must supply to the payload. Finally, the payload specialist activates the experiments and monitors all of the payload's subsystems and the quality of the collected data.

Crew and passengers will work in shirt sleeves, in an atmospheric environment much like that on earth. Cabin air is a nitrogen-oxygen mixture at a sea-level pressure of 14.7 pounds to the square inch. (Apollo crews used pure oxygen at 5 psi.) Heat-stabilized and freeze-dried foods, as well as advanced personal-hygiene facilities, bring the comforts of home to the Shuttle. Electrical power is furnished by three 12-kilowatt hydrogen-oxygen fuel cells.

Launch pad in the sky

For missions using a modularized spacelab loaded in the bay, the dual payload doors are first swung open. This offers a clear view for the spacelab's astronomical or earth-viewing instruments. Spacelab equipment is mounted on an open pallet forming the aft portion of the lab. Its front end has a drum-shaped, pressurized room used by scientists for observation and instrumentation control.

The spacelab, to be specially equipped for each mission, is being funded and developed by the European Space Research Organization. Prime contractor is Entwicklungsring Nord (ERNO) of Bremen, but there are associate contractors from several other European countries.

The Shuttle will also transport unmanned satellites into orbit and leave them behind. After the payload doors are opened, long mechanical "manipulator arms" lift the spacecraft from its berth. Outside, but operated from within the shuttle, crucial spacecraft subsystems such as solar arrays, antennae, attitude controls, sensors, and transmitters are deployed, activated, and monitored. The spacecraft is released only after ground stations report that they receive a good data stream. Faulty spacecraft can be returned to earth for repair.

Shuttle craft will also have rendezvous and docking capabilities, enabling them to revisit complex spacecraft such as the upcoming Large Space Telescope (LST)—an orbiting "Palomar in the Sky." Such a valuable instrument must be designed for several decades of useful life. But since no one can predict the most interesting science objectives that far in the future, manned visits will be necessary between major science assignments for updating, reprogramming, and changing equipment. The LST will be unmanned between visits.

A docking module placed in the Shuttle's cargo bay would enable personnel to move directly from the pressurized crew compartment to the LST's pressurized instrument module. For high orbits or unmanned lunar and planetary missions, spacecraft carried in the Shuttle's bay will have propulsion units called "tugs" attached to them. After arriving in a low orbit, the tug/spacecraft combination is lifted from the bay. The shuttle then withdraws to a safe distance and the tug engine is ignited, boosting the spacecraft into higher orbit or into an escape trajectory.

Tugs will be used to reach the 23,200-mile geosynchronous orbits in which satellites match the earth's revolution and thus appear to stand still. Future high-energy tugs may lift 8000-pound spacecraft into synchronous orbits. Yet the total launch costs for such missions, some $15 million apiece, is less than half those of a Titan IIIC rocket, which is limited to payloads less than 4000 pounds.

Before a special high-energy tug is built, however, three proven upper stages of existing rockets may serve as interim tugs. One is the Titan IIIC's "transtage," specifically designed to boost payloads into higher orbits. Two other possibilities are the Agena and Centaur stages.

A modified version of the Shuttle can also be used to loft very heavy payloads for special missions. In this

[*Continued on page 136*]

Reusable space shuttle

[Continued from page 73]

configuration, the Orbiter will be replaced by the payload itself, up to 200,000 pounds, for a one-way trip. The Orbiter's three engines would be placed at its aft end.

Leaving orbit

The basic Shuttle can remain in orbit seven days, but with extra provisions and a reduced payload, the stay can be extended to 30 days. When the mission is completed, commander and pilot return to their flight stations and position the Orbiter for reentry. Using the reaction-control thrusters, they roll the Shuttle into a heads-down, aft-facing position. At a precise moment they fire up the two OMS engines and begin their flight home.

Skimming the upper layers of the atmosphere, the Orbiter is again turned around to a heads-up, forward-facing position. At a 76-mile altitude, control is gradually transferred from rocket thrusters to the aerodynamic surfaces. The Orbiter is traveling at 17,500 mph with its nose pitched up.

To protect its aluminum structure from blazing reentry heat up to 3000°F, the Orbiter is covered with three different types of heat-insulating materials (see drawings, page 72).

The Orbiter has a cross range of 1100 miles, which means it can reach a runway not exceeding that distance on either side of the orbital plane. Banking the Orbiter right or left enables such glide-path corrections to be made. Guidance during the reentry glide is provided by an inertial-navigation system that can either be tied into the orbiter's autopilot or to a cockpit display for manual control.

The first phase of the glide is completed at 70,000 feet. Traveling at about Mach 1.5, the Orbiter arrives within a circular area about nine miles in diameter. As the vehicle descends to 10,000 feet, its speed is stabilized at about 345 mph with the help of split-rudder speed brakes.

"Dead-stick" landing

Since there is no propulsion for a go-around maneuver, the Orbiter must land "dead stick" on the first approach. A microwave landing system guides the approaching Orbiter along a prefixed glide path. As Orbiter draws to within five miles of the 15,000-foot runway, its remaining potential and kinetic energy must be carefully managed. This is done with the aid of an "energy-management" computer. TV-like displays in the cockpit cue the flight crew to initiate the final runway lineup.

As the descent continues, between 10,000 and 2000 feet, the glide slope is a very steep 20°. Flaps and landing gear are lowered at 2000 feet, gradually shallowing the descent to 3°. Air speed diminishes from over 300 mph to about 215 mph at touchdown. The crew can override the automatic landing approach.

Failsafe operation

The Space Shuttle is heavily equipped with backup equipment, so a disaster is even less likely to occur than during our successful Apollo flights. Nevertheless, three abort modes have been planned for launch phase. If a main engine fails early in the launch, the flight will continue until solid booster burnout. After the booster casings are jettisoned, the crew will head back to the launch site, dropping the Orbiter's external tank and shutting off the engines when a gliding descent becomes possible. Both OMS engines can then be used for flight-path corrections.

If trouble develops later during the ascent, the Orbiter will be flown around the earth once at suborbital speed before landing. A third abort mode, to be used when there is no immediate safety threat, would postpone investigation of the problem until arrival in orbit. NASA decided, after careful analysis, that a launch-pad escape capability would not be needed.

Early in 1977, the first phase of a flight-test program is slated to begin at Edwards AFB, Calif. An Orbiter will be carried piggyback on a 747 aircraft to the cruising altitude of conventional airliners. The carrier will then begin a shallow dive while the Orbiter nose is raised with a hydraulic jack. This will enable the Orbiter upon release to glide off the back of its mother craft. These tests will be flown by two-man flight crews, equipped with traditional ejection seats.

A second test phase from NASA's John F. Kennedy Space Center should begin in late 1978. Two-man crews will ride a Shuttle into low earth orbit. Then two Orbiters will be refurbished for operational use and the final phase of the Shuttle program will be underway. PS

1975

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Popular Science

The What's New magazine

The U.S.-Russian linkup in space
By Wernher von Braun

New machines let scientists see inside the human body

How to guard against auto-repair ripoffs

New tape recorder lets you speed up playback yet understand every word

We get set for Astronaut-Cosmonaut space linkup

Our next manned flight in 1975 will be to team up with our former Soviet rivals—and may lead to joint super-adventures in space

By WERNHER von BRAUN
PS Consulting Editor, Space

An earlier article by Dr. von Braun, following first official announcement of the joint Apollo-Soyuz 1975 mission, outlined initial plans for it [PS, Aug. '72]. Here he brings its story up to date with new details of the approaching flight.—The Editors

On July 15, 1975, at 3:30 p.m. Moscow time, a USSR Soyuz spacecraft manned by two cosmonauts will be launched into a 167-mile-high orbit, from the Baikonur cosmodrome in central Asia.

Seven and a half hours later, as the Soyuz passes overhead, a Saturn IB rocket will take off from the Kennedy Space Center in Florida, with three astronauts riding in pursuit in a slightly modified Apollo Command Module. After about two days of orbital adjustments, the Soyuz and Apollo will rendezvous and dock.

For the next two days the two spacecraft will remain linked together. The U.S. and USSR crews will visit each other's spacecraft, and perform joint experiments. They will communicate with their respective mission-control centers, and NASA's new Applications Technology Satellite 6 will serve as a relay for almost uninterrupted worldwide TV transmissions from aboard to spectators on the earth.

When joint experiments are completed, the two spacecraft will separate, and practice a few more linkup maneuvers. Thereafter each craft will go its own way to the completion of its flight. Ultimately the Soyuz will descend on land in USSR territory, and the Apollo will come down later in the Pacific Ocean.

This flight plan, giving Apollo the active role in maneuvers to a linkup, revises an earlier one [PS, Aug. '72] that would have launched Apollo first.

Joint mission opens vistas

The dual flight will demonstrate that U.S. and USSR scientists, space engineers, and astronauts and cosmonauts—rivals for the past 15 years—can also work as a team, and do difficult things together. But that history-making extension of U.S.-USSR detente to space is not all. It may well set the stage for future international space missions so ambitious that they can be accomplished only by pooling the resources and talents of the two countries, and possibly of others as well. (For some imaginable examples, see last column on concluding page.)

When Soyuz and Apollo were conceived a decade ago, the two spacecraft-development teams followed their own independent criteria, hunches, and engineering philosophies. The Soviets selected an airlike cabin atmosphere—a nitrogen-oxygen mixture at a pressure of 14.7 pounds per square inch, equal to sea-level atmospheric pressure on earth. For Apollo, we chose pure oxygen gas at a pressure of only five pounds per square inch.

For a docking mechanism, the Soviet engineers came up with a ring-and-petal design having the advantage of no centrally located parts to be moved out of the way, to clear the passage between two docked spacecraft. We selected a probe-and-drogue design—much lighter, but a bit awkward because parts must be removed after docking to provide a free passageway between spacecraft.

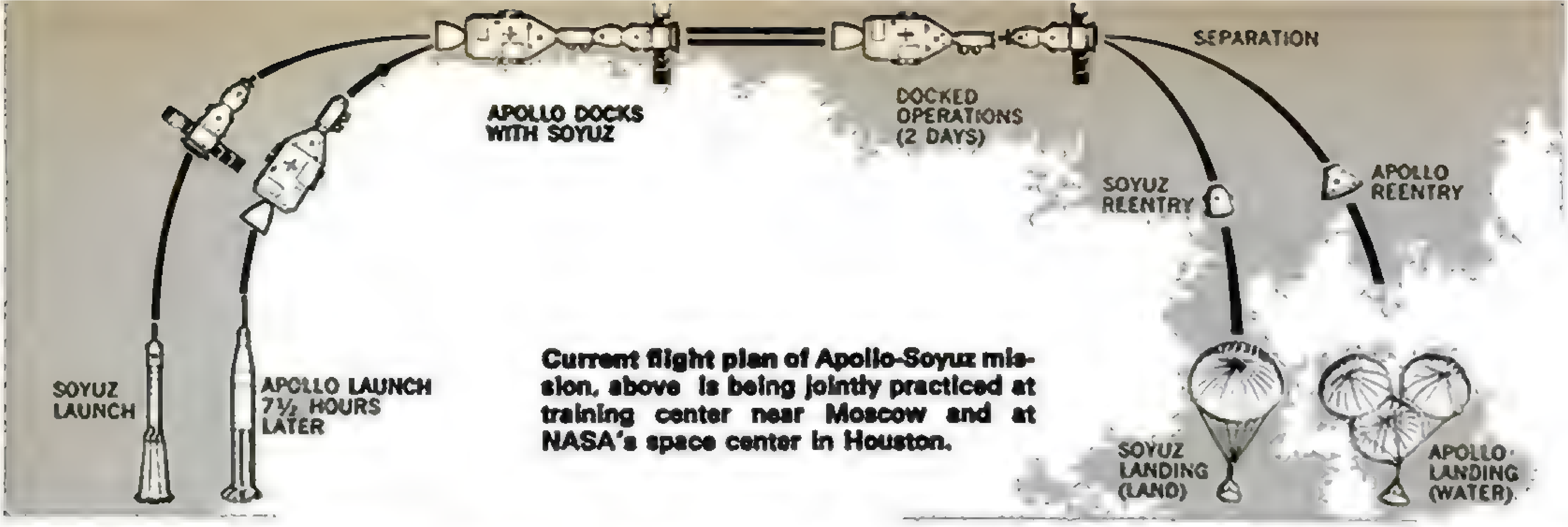
To change either the basic Apollo or the basic Soyuz would have required a series of costly reverification tests, including several manned flights. It would have deprived both sides of confidence in their proven designs, and substantially added to the risks of the joint venture.

Docking Module bridges gap

So it was wise and economical to create, instead, an adapter element called the Docking Module, which can dock with the Apollo Command Module at one end and with the Soyuz at its other end. This new piece of space hardware, a cylinder five feet in diameter and 10 feet long, will also serve as an airlock to permit crewmen to go from one to the other of the two differently pressurized craft. It is large enough to hold two space-suited astronauts or cosmonauts, but they will normally make the transfer between spacecraft in shirtsleeves. Built for NASA by Rockwell In-

Continued

Color painting of linkup, opposite page, shows Apollo (top), pushing Docking Module ahead of it, about to dock with smaller Soyuz in 167-mile-high orbit.
PAINTING BY BOB McCALL



Current flight plan of Apollo-Soyuz mission, above is being jointly practiced at training center near Moscow and at NASA's space center in Houston.

In Russia: Commander Stafford (foreground) of American team for Apollo-Soyuz mission joins Soviet team's commander, Leonov, in mockup of Soyuz spacecraft. Maybe they're laughing over struggles of U.S. crewman Deke Slayton to fit his lanky frame into Soyuz capsule's close quarters.

In U.S.: Russian team's commander Leonov (in foreground) tries out Apollo spacecraft's quarters at Houston space center. Interpreter at his right relayed astronauts' talk before the two crews learned each other's language. Leonov's teammate Kubasov is seen in far background of photo.

ternational, it was delivered last September.

At the time of launch the Docking Module will be carried aboard the Saturn IB, in the conical section between the Saturn instrument compartment and the aft end of the Apollo Service Module. In a Saturn V lunar launch, the same section accommodated the Lunar Module. Upon arrival in orbit, the Command and Service Module will separate from the Saturn IB, turn around, and extract the Docking Module from its berth, just as the Lunar Module was extracted after translunar injection.

Pushing ahead of itself the Docking Module attached to its nose, the Command Module will finally rendezvous and link up with the Soyuz. To make this possible, extensive coordination between both sides has been necessary on such details as the search-and-approach system, common radio communications, beacons, signal lights, and optical docking aids.

While the spacecraft are docked, the Soyuz pressure will be reduced from its normal 14.7 pounds per square inch to 10 pounds. This will enable crewmen to transfer from Soyuz to Apollo without taking excessive time in the Docking Module to breathe pure oxygen and force nitrogen from their blood.

Crews picked for mission

Commander of the Soyuz will be Col. Aleksei A. Leonov, who was the first man to "walk" in space, during the flight of Voskhod 2 in March 1965. His crewmate will be Valery N. Kubasov, a civilian engineer, who was a member of the Soyuz 6 crew in 1969.

Skipper of the American craft will be Air Force Brigadier General Thomas P. Stafford, veteran of two Gemini flights and of the Apollo 10 mission, which demonstrated rendezvous and docking in lunar orbit—the final dress rehearsal for the epochal first lunar landing.

Riding up with Tom Stafford will be Vance D. Brand, a space rookie, and Donald K. (Deke) Slayton, who has never been in outer space either, but probably knows more about the crew problems of manned space flight than any other astronaut. Ever since the early Mercury days, he has served as director of flight-crew operations in Houston or, as he puts it, as the "mother hen" of the fledgling astronauts.

Deke would have been an early astronaut himself, but was grounded when an electrocardiogram revealed a slight heart irregularity—reportedly common, and trivial except by space doctors' or flight surgeons' extremely rigorous standards. Now the medics have changed their minds and given him a long-hoped-for green light.

Experiments alone repay costs

Even without taking into account the momentous political and long-range aspects of the Apollo-Soyuz Test Project (ASTP), its program of experiments will make it worth every penny of its $250-million price tag.

Within the last year a varied selection of joint Apollo-Soyuz experiments—some proposed by each country—has been agreed upon and definitely scheduled. Additional experiments will be performed by the Apollo crew alone, during the six days or so it remains in orbit after parting company with Soyuz.

Astronauts and cosmonauts, using a small electric furnace, will jointly perform one of a series of some half-dozen space manufacturing experiments—to be completed later by the Apollo crew alone.

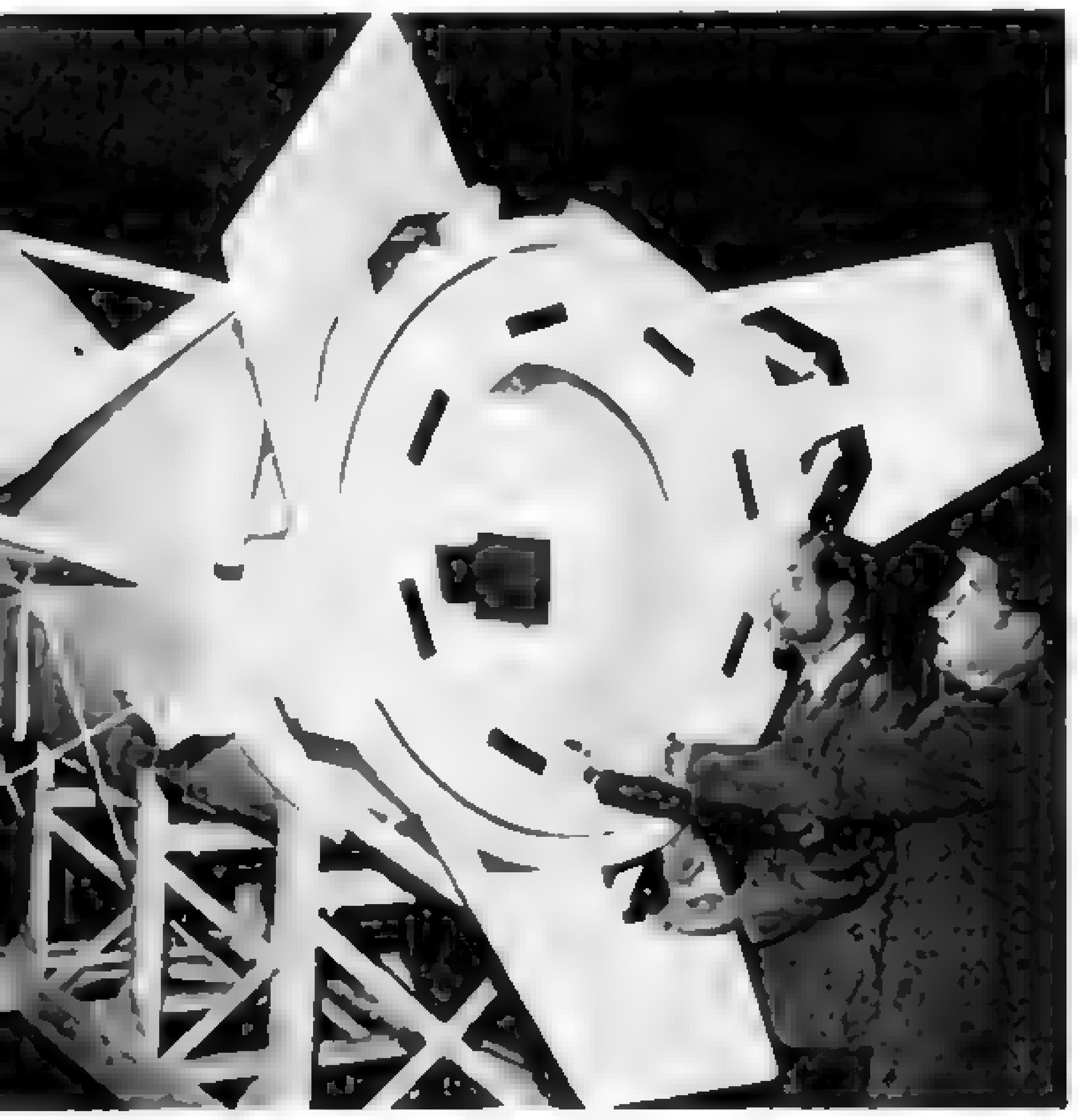
They include trials of producing improved magnetic materials and crystals of various semiconductor materials in the weightlessness and vacuum of space.

An artificial eclipse of the sun will be produced by positioning Apollo so that cosmonauts in Soyuz can photograph the solar corona.

Other joint experiments include a new way to gauge the density of the tenuous atmosphere at orbital altitude, by noting absorption of ultraviolet rays transmitted from Apollo and bounced back by Soyuz.

On its own, Apollo will make experiments testing the possibility of producing improved vaccines and serums in space for use on earth. It will seek to measure local earth-gravity anomalies to aid studies of mineral resources, earthquakes, volcanic activity, and continental drift. A multitude of experiments in astronomy and life sciences will complete the ambitious program designed for the mission.

Because of the ASTP's international nature, the training for its crews of astronauts and cosmonauts is unique. Leonov and Kubasov have spent many weeks in Houston, while Stafford and his men (as well as the Apollo backup team consisting of Alan L. Bean, Ronald E. Evans, and Jack R. Lousma) have been familiarizing themselves with equipment and taking simulator training at the Gagarin Training Center in Zvyozdni Gorodok ("Star City"), 35 miles east of Moscow.



New piece of space hardware, the Docking Module, plays key role in joint mission. It's both an adapter for incompatible U.S.-USSR docking gear, and an airlock for crewmen's passage between different atmospheres in the two craft. Near end of full-scale mockup above, displayed by Rockwell International, shows ring-and-petal docking gear.

In these training sessions, astronauts and cosmonauts, wearing similar yellow, green, and blue coveralls emblazoned with a special Apollo-Soyuz emblem, are on professional, friendly, first-name terms. They find that their communications will be most effective when the cosmonauts speak English, and the astronauts talk Russian.

Both crews have made great progress in learning the other's language. At a press conference in Houston last April, Tom Stafford surprised his audience with a fluent address in Russian, while Leonov fielded reporters' questions in flawless English.

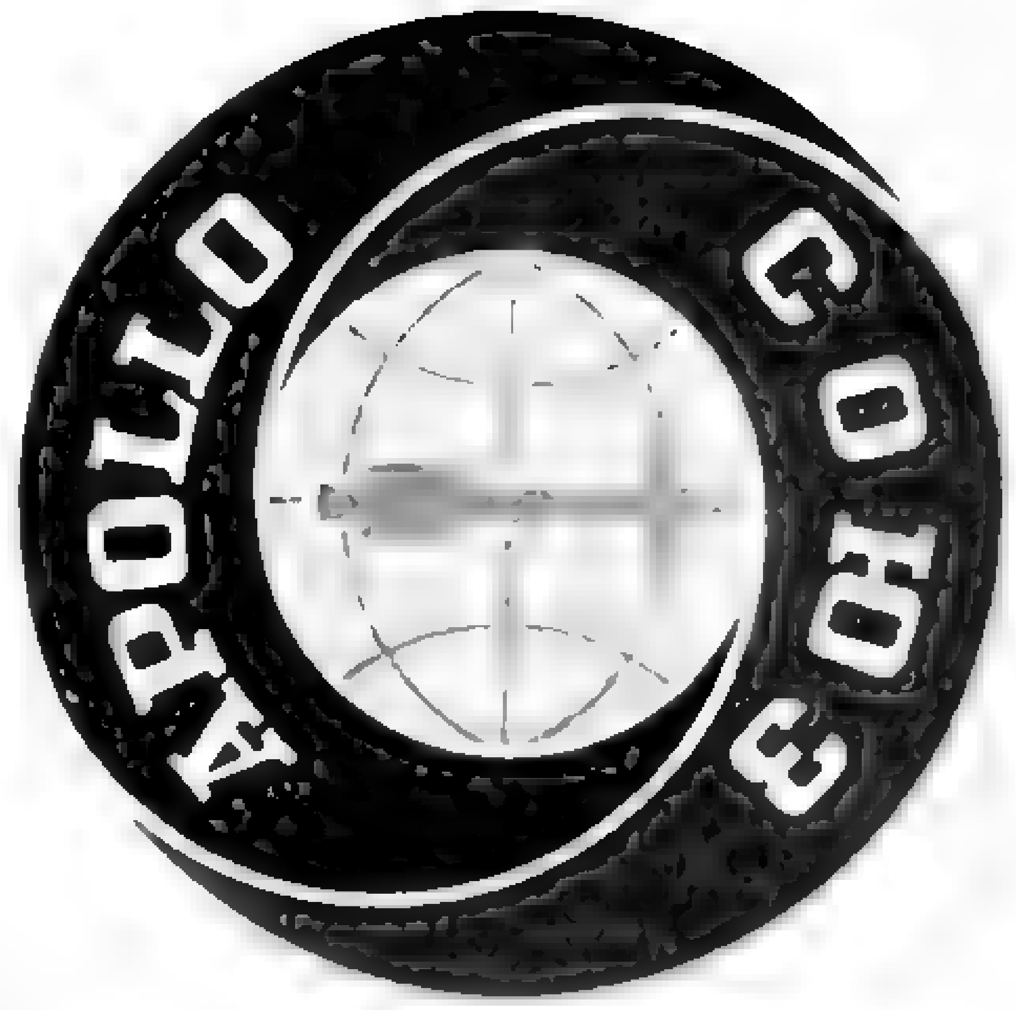
Down go former barriers

Joint training sessions are by no means limited to the flight crews. On the basis of "technical necessity," American flight controllers will be seated at some consoles of the Soviet mission-control center, and vice versa.

Unlike our own launch facilities at Kennedy Space Center in Florida, which have been seen by millions of American and foreign tourists, Soviet launch complexes at Baikonur have been strictly taboo for any outsiders in the past. It was another sign of the emerging team spirit of the project when Leonov, at a Houston press conference early this year, announced that American ASTP astronauts would soon be invited to visit the Baikonur cosmodrome. He added that he was looking forward to visiting the Kennedy Space Center himself. An open invitation to that center had always been declined by Soviet spacemen before, because of their inability to reciprocate.

NASA recently decided to use an improved ring-and-petal docking system, developed for the ASTP Docking Module, as the standard linkup mechanism for the Space Shuttle too. Compatible with this new docking gear will be the Shuttle's primary payload for manned science and application experiments, the Spacelab being developed by Europeans.

Standardized coupling devices are not only a necessity for mutual-assistance and rescue operations in space. They are an absolute "must" for any major joint international space ventures—for which, it is hoped, the Apollo-Soyuz Test Project will lay the groundwork. Perhaps the most significant of all the 1975 mission's experiments may be its first trial in space history of a prototype of the compatible docking mechanism of the future. PS



Official emblem for Apollo-Soyuz flight, jointly chosen by U.S. and USSR, shows linkup and names of both spacecraft—Soyuz, in Russian.

What could Apollo-Soyuz lead to?

A joint U.S.-USSR communiqué, on results of the Nixon-Brezhnev summit conference last summer, officially confirms that the two nations will "continue to explore possibilities for further joint space projects" to follow the Apollo-Soyuz flight in 1975.

Here is a sampling of ideas unofficially proposed for U.S.-USSR joint space ventures to come. Since no definite commitment for any has been announced at this writing, all of course are still somewhat speculative:

- An international space station, jointly manned by astronauts and cosmonauts, to succeed our Skylab and the Russians' Salyuts.
- A manned base on the moon, including an astronomical observatory and a complex of long-habitable structures, to be established by the U.S., the USSR, and Europeans. Our coming Space Shuttle could serve as a launch vehicle. (This project was suggested to a Senate space committee by NASA Administrator James C. Fletcher. Russian views, he noted, were still to be invited.)
- An unmanned mission to Mars to return samples. The Russians have successfully done it on the moon. The attempt might possibly involve remote-controlled roving vehicles, also successfully demonstrated on the moon by Soviet Lunokhods. NASA has studied a conceptual design and operating characteristics for future Viking-borne Mars rovers.
- A manned expedition to Mars. It may be too costly for any single nation, but entirely feasible in the future as an international super-adventure.

—W. v. B.

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Popular Science

The What's New magazine

EGGBEATER WINDMILL

...self-starting, cheaper to build

PS guide to hundreds of free vacation areas

Rustproofing your car

How to get into scuba diving

The truth about in-home clean-water devices

Beginning a three-part series on ENERGY FROM THE SEA
This month: waves, tides, and currents

...plus many other timely articles, What's New Digest and 11 every [illegible] features

von Braun takes a

trip to the moon

in a simulated spaceship—and so can you

The world's largest space exhibit now offers you the thrills of a lunar voyage. Here's a first-hand report of a passenger's reactions and the sights he sees—and a behind-the-scenes peek at how it's all done

By WERNHER von BRAUN
PS Consulting Editor, Space

HUNTSVILLE, ALA.

This is your flight captain speaking. We'll be lifting off from Huntsville Space Center shortly. . .Our destination is Lunar Base One, the permanent station in the Descartes Mountains of the moon.

The scene is the Alabama Space and Rocket Center, the world's largest space exhibit. I have just buckled myself into one of the 45 red passenger couches of its latest attraction—the make-believe spaceship Lunar Odyssey—for a simulated voyage to the moon.

The time is imagined to be some fifty years in the future, when flights between earth and moon have become frequent and regular.

Futuristic electronically synthesized "space music" has lowered as the captain's voice comes over the public-address system's loudspeakers. Now you hear another voice:

Lunar Odyssey, this is Launch Control. All systems are go—we're proceeding with the countdown. Coming up on the final count. . . ten. . . nine. . . eight. . . seven. . . six. . . five. . . four. . .

The thunderous roar of booster engines smites your ears as the captain reports:

We have ignition.

An invisible force thrusts you back against your couch. Actually the whole drum-shaped "spaceship" is now revolving, becoming a human centrifuge that realistically simulates the sensation of a rocket ship's acceleration. Try to extend your arms when the drum has reached full speed, and they are pushed right back again.

On a planetarium-type dome overhead, you see movies of what is supposed to be happening—the Lunar Odyssey streaking aloft after liftoff. (Actually the film is a long-range tracking camera's

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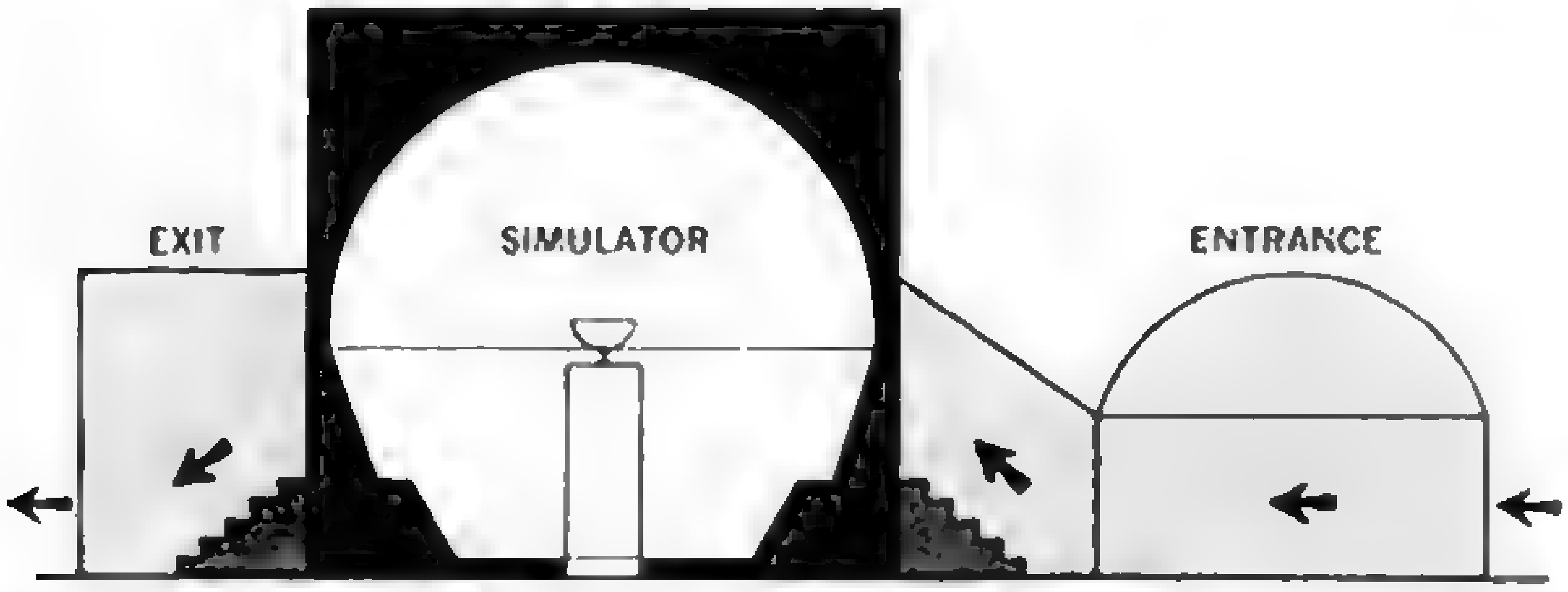
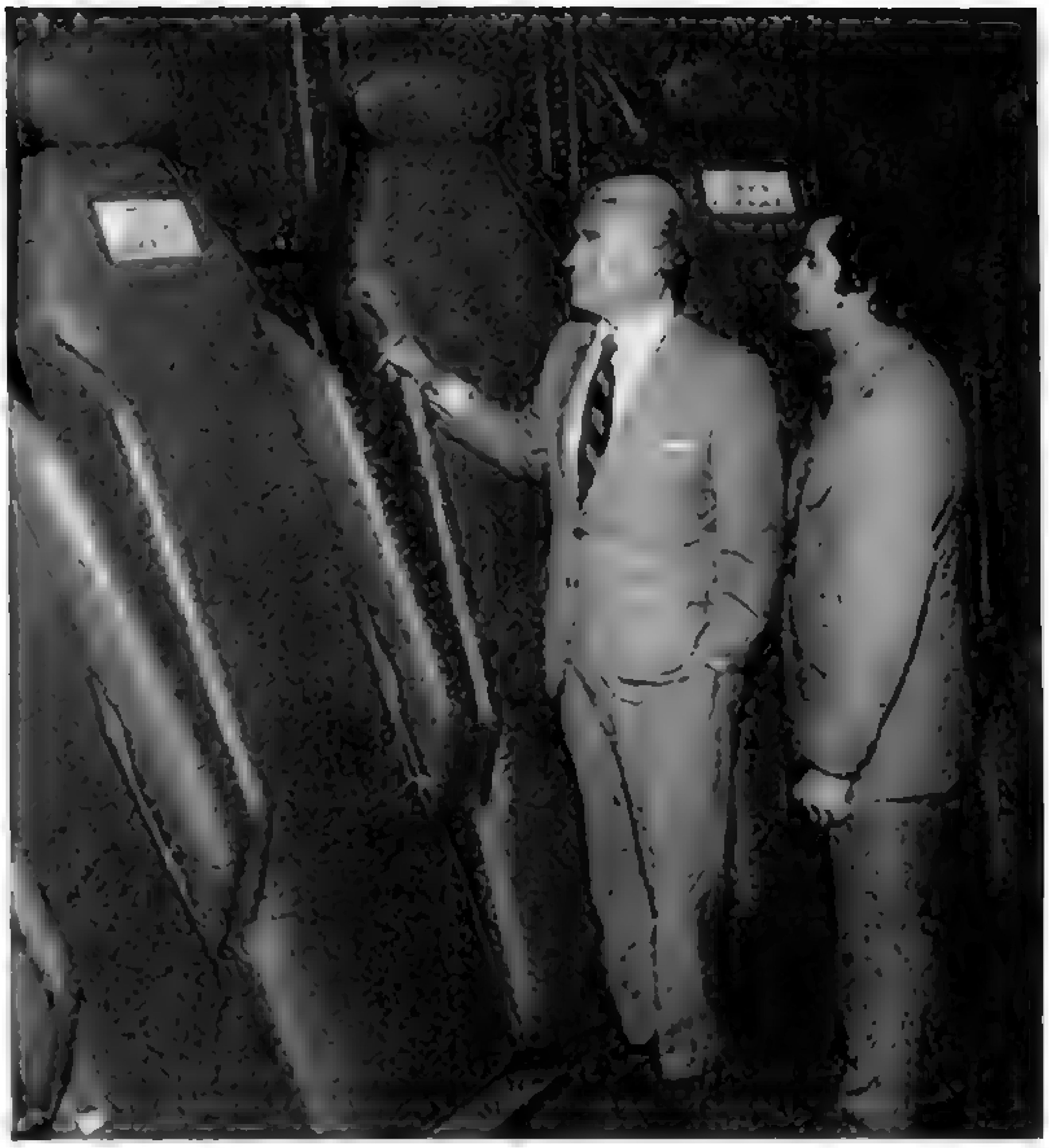


About to board the Lunar Odyssey, author stands at entrance (far right) leading to simulated moon ship. Simplified cutaway view of its special building, entrance, and exit is shown in diagram above

Moon ship Lunar Odyssey, pictured in color on opposite page, takes up to 45 passengers and captain at center on a simulated lunar voyage. Passengers' inclined couches, whirling as in a human centrifuge, give realistic sensation of increased g-force from rocket ship's acceleration, and sound effects indicate firing of booster and upper-stage rocket engines. During the passengers' exciting ride, projectors hidden in bowl above captain throw pictures of receding earth, passing sights like Skylab, stars, and close-up view of moon's surface on planetarium-like dome at top of ship. Their drum-shaped craft measures 31 feet in diameter, about 30 feet high.



Dr. von Braun, in captain's seat of Lunar Odyssey moon ship, views controls pointed out by his escort, Edward O. Buckbee, director of Alabama Space and Rocket Center. Above, they inspect the passenger couches before buckling up for "trip to the moon," with sights and sensations experienced until now only by astronauts.

view of a Saturn V rocket in flight.) Your captain announces:

Standing by for booster separation. We'll be watching it on the screen.

In the movies on the dome, the spent booster drops away with a synchronized clanking sound effect. Now you hear a roar of higher pitch, indicating that smaller and nearer rocket engines of an upper stage have taken over. Your skipper informs the ship's passengers:

We're now escaping the gravitational pull of earth, and there below us is a distant view of Mother Earth. We're leaving her at a speed of 25,000 miles an hour.

On the dome you see our receding planet, a beautiful blue globe in the black, star-spangled sky. For the first time you notice that you and your couch have risen 10 inches from the floor, as if floating freely in space.

Sights of space follow in succession on the dome. Your ship goes by the orbiting Skylab space station, launched in 1973, and the captain comments:

That was a long time ago, but our astronauts lived and worked for months at a time in Skylab, paving the way for our flight today. . .As we continue our course

Couch and passenger rise 10 inches from floor, as if free-floating, during trip. Overhead view reveals springs and elastic roping that give initial lift.

Motive power to whirl the moon ship comes from husky 15-hp electric motor, at right in front view of drive. Through belts and pulleys, it turns a rubber-tired drive wheel in contact with a 36-inch-diameter disk on bottom of ship, silently imparting a variable speed that ranges up to maximum of about 20 rpm.

to the moon we'll pass the International Space Station launched in 1993 as a cooperative effort by many nations. . .The station is a permanent outpost halfway between the earth and the moon.

Soon it comes into view—a huge wheel-shaped space station, slowly rotating about its axis.

And now, the moon

There is a midcourse correction. The ship seems to wheel around and the distant moon comes into view. The craft's winning battle to escape the earth's gravity has cost most of its initial speed.

We're approaching the moon at about 5000 miles an hour. I'll maneuver the spacecraft now to get into position for firing our main engine to obtain orbit of the moon.

You hear a rocket blast to brake your now-turned-backward craft so the moon will capture it.

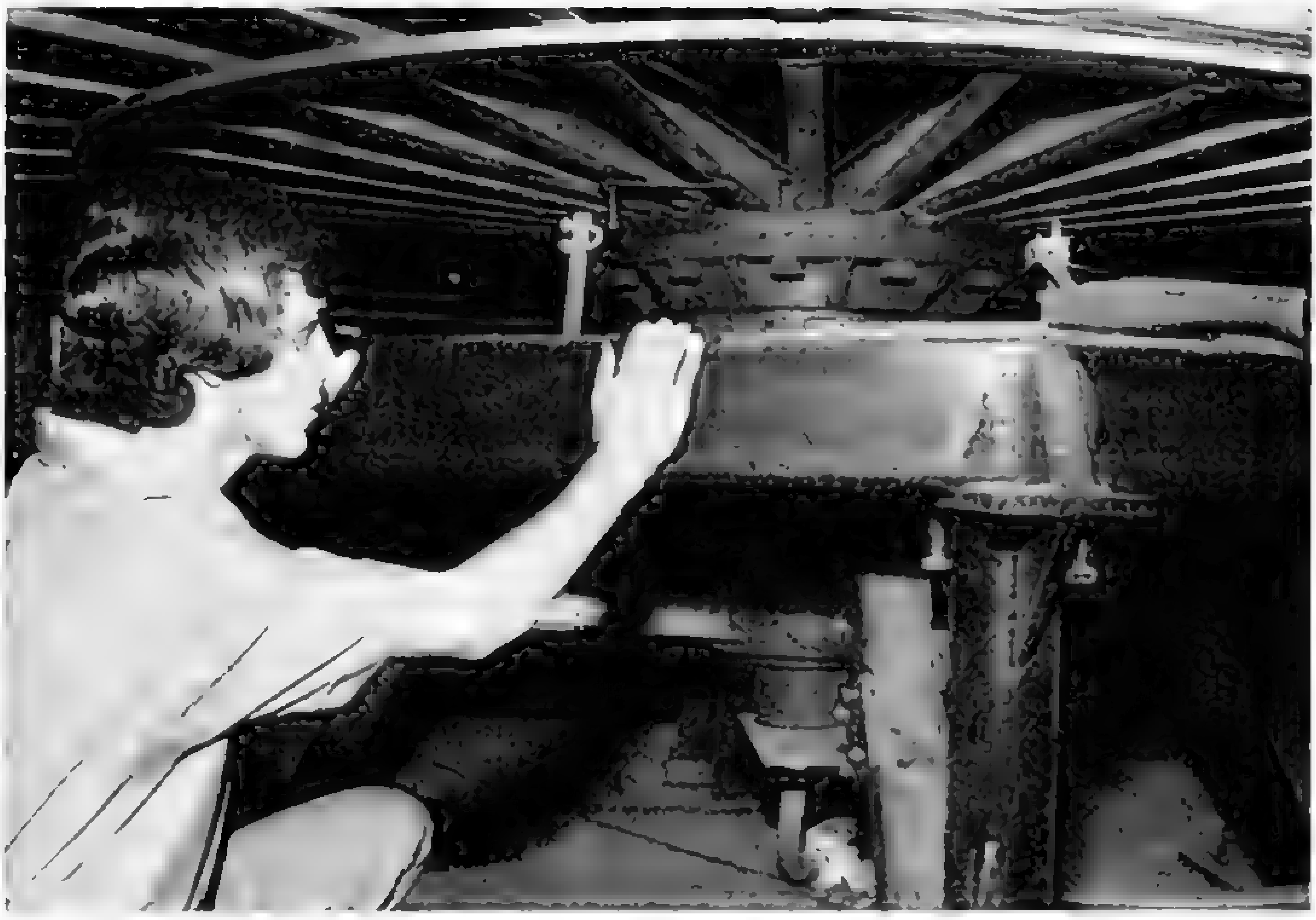
Engine firing complete. We're in lunar orbit. You're viewing the lunar surface as we pass over the moon at sixty miles' altitude.

Pictures of the breathtaking lunar scenery pass before your eyes. Again comes the sound of retro-firing and Lunar Odyssey starts down toward the surface—at first gradually, and then vertically, supported by its rocket engine on the way to a gentle landing. During descent your couch drops back

[Continued on page 130]

Astronauts for a day, tourists enjoy thrills of Lunar Odyssey's simulated voyage to the moon, in view at right. Their captain is seated in left foreground.

At opposite end of drive, rubber-tired drive wheel turns disk on ship's undercarriage. Similar idler wheels steady the ship and help brake its rotation.



Hub of rotating ship rests on this central bearing. At top of view is turntable beneath the "flight deck" for the passengers and captain. The drive wheel and two idler wheels have hydraulic brakes to slow or stop the rotation that simulates the g-force of an accelerating rocket ship on the way to the moon.

Trip to the moon

[*Continued from page 95*]

again toward the spaceship's deck.

Lunar landing at Lunar Base One in 60 seconds. I'll switch to the descent camera so you can observe our landing maneuver.

Meanwhile your skipper tells you more about the lunar base of the future, whose Descartes Mountains region was explored by astronauts of Apollo 16 in 1972:

Lunar Base One was established as a permanent station on the moon in the year 2024. It's become an important research and manufacturing center helping to support our needs on earth. . . At the present time we have about 150 people stationed here working in manufacturing, medicine, geology, mineralogy, and other fields . . .Stand by for touchdown.

The sound of the braking engine stops.

Contact light on. . .Landing is complete. We're now on the moon . . .The airlock is being attached and the atmosphere is being equalized so that you may enter Lunar Base One. . .

As if leaving a plane by a walkway drawn up to its door, you disembark from the Lunar Odyssey through the "airlock."

The Lunar Odyssey's design

The drum-shaped moon ship measures 31 feet in diameter at its widest point, and about 30 feet high to the middle of the dome. It accommodates up to 45 passengers at a time, plus the captain at the center, on its "flight deck." Passenger couches are arranged in an inner and outer circle. Passengers experience 1½ g's in the inner circle, and two g's in the outer one, as the ship whirls at a top speed of about 20 rpm. The couches tilt backward about 12 inches at launch.

The captain advises passengers to avoid moving their heads from side to side because it would destroy the sensation of straightaway acceleration, and could have uncomfortable consequences too.

In man's inner ear are two special organs called otoliths, essentially little plumb bobs that tell you which way is down. Hold your head steady and they cannot distinguish between a linear acceleration and the Lunar Odyssey's centrifugal acceleration.

The moment you move your head, however, the plumb bobs tell you that you are not really moving in a straight path, but going around in a circle. The result can range from mild nausea to severe dizziness. But as long as you don't move your head, there will be no problem.

What's backstage

Sights seen by the passengers are thrown on the dome by a pair of projectors in a bowl above the captain's seat. The pictures look steady to viewers since projectors, passengers, and dome all revolve at the same speed.

The secret of the passengers' rising couches is hidden behind them. Each couch is free to move up or down on a track. Springs and elastic ropes provide an initial lifting force, and the addition of centrifugal force does the rest. True weightlessness, free of g-force, couldn't be simulated on the earth's surface; but the rising couches offer an exciting substitute.

Behind the scenes, silent motive power for revolving the ship is provided by a 15-hp electric motor through one of several rubber-tired wheels in contact with a driving disk on the ship's bottom.

The Lunar Odyssey's driving mechanism was designed and built by the staff of the Alabama Space and Rocket Center, owned and operated by the state of Alabama as a public exhibit.

All comers are welcome to take the same thrilling Lunar Odyssey ride that I did. There is no separate admission for the moon trip. You're entitled to enjoy all the center's many attractions, the Lunar Odyssey included, for a single modest admission fee—at the time of my recent visit, $2 for adults and 95 cents for children.

The "moon ship" operates every half hour in summer and on the hour in winter, seven days a week, from 11 a.m. to 5 p.m.

Naturally the Lunar Odyssey takes the liberty of compressing the duration of a real lunar voyage. The simulated one has an actual elapsed time of 10 minutes.

If you visit the Alabama Space and Rocket Center, you'll do well to allow ample time to take in its other sights, too. A space buff could easily spend at least a day enjoying them, with time out for refreshment at one of the center's snack bars. (Both sandwiches and space food are on the menu.)

More sights to see

In an outdoor "rocket park" you'll see actual rockets and missiles of every description. Most impressive of all is a full-scale

Saturn V-Apollo space vehicle, the only one on public display in the world. Laid on its side so you can walk right up and touch it, the 363-foot monster stretches the length of a football field. Once used for ground tests, it's a sister ship to the ones that launched Apollo astronauts to the moon.

A simulated 100-foot-diameter lunar crater is an accurate likeness of a real one. You can climb the steps of a Lunar Module—like the one from which men took their first steps on the moon—sitting near its center.

The center's main exhibit building displays famous U.S. spacecraft and a Russian one. You're invited to pretend you're an astronaut in a wing filled with do-it-yourself action exhibits. You can fire a real rocket engine, check your heart rate on an astronaut's monitoring system, and "fly" a Lunar Module with a moon-landing simulator.

You can meet the "first lady in space," Miss Baker—a squirrel monkey who rode a Jupiter rocket in 1959. Now happily married, she and her mate Big George live in a comfortably air-conditioned "monkeynaut" chamber at the center.

A visit to Skylab

You can also buy a ticket and take a bus from the Alabama Space and Rocket Center for a two-hour guided tour of NASA's Marshall Space Flight Center, which is at Huntsville, too, and just a few miles away.

Marshall (which I formerly directed) was the birthplace of America's first satellite, Explorer I. Between 1961 and 1972 its space team was in charge of providing the huge Saturn V rockets for Apollo moon landings. Marshall's latest baby was Skylab, our first space station. The tours' visitors can walk through a mockup of Skylab there. So they can safely view the crew compartment and its facilities for working, eating, and sleeping, it has been modified for their benefit. An access door in the side has been widened, a floor has been added, and handrails have been placed inside.

Marshall, with its demanding tasks of development and management, could never have accommodated all the tourists who want to see and touch the wonders of the Space Age. That's why the state of Alabama established the Alabama Space and Rocket Center. More than a million visitors have passed through the Center since its 1970 opening. PS

'75 garden tractors

[Continued from page 111]

pour. Dirt, even a few microns in size, can ruin a hydro.

Described as automatic drives or shuttle drives, these can be spotted when you see a basic belt drive from the engine to a three- or four-speed gearbox but with an intermediate, movable idler system that looks more complex than a simple belt clutch. Shuttles give you direct reverse and a built-in variable operating range that feels much like a hydro [PS, Feb. '72]. Basically, one pulley hub has internal planetary gears and the other pulley is split to act as a clutch.

Still another way to vary speed and torque smoothly is with the variator on John Deere's 200 series. When you move a lever, or depress the clutch all the way, you change the tension on the primary drive belt from the engine. This forces a movable center flange on the variator sheave to slide sideways, changing the working diameter of the sheaves and thus altering the reduction ratio.

It depends on what you use a tractor for, and on personal preferences. For heavy, hard, ground-engaging work, my own preference is for a multirange gear drive, such as a Gravely or Economy. For very close careful maneuvers, a clutch that can be slipped is easier to control than a hydro, which often tends to jump. But for flitting about the yard, grass-cutting and snow-throwing, hydros are handiest because of instant speed control and reverse.

For lighter lawn tractors used mostly for mowing, buy one with a transaxle that can be shifted on the run. It's annoying to stop and putter with a balky shift lever every time you want to go faster or slower.

If you have sloping ground, beware of brakes on the transmission rather than on the wheels. A broken final drive, be it chain or key, leaves you no way to stop. And with some drives a shift through neutral on a hill can start you on a deadly backward roll. Brakes that actually restrain the wheels, not the axle or drive line, are safest.

So, if you're shopping, the engines are all good. It's what's between the engine and the wheels that counts. Look underneath and try before you buy. It's hard to go wrong in '75. PS

JUNE 1975 75 CENTS

Popular Science

The What's New magazine

TWO LITTLE ELECTRICS

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ENERGY FROM THE SEA
The big push to tap its vast reservoir of solar heat

Electronic supermarkets: how the new automatic checkout systems work

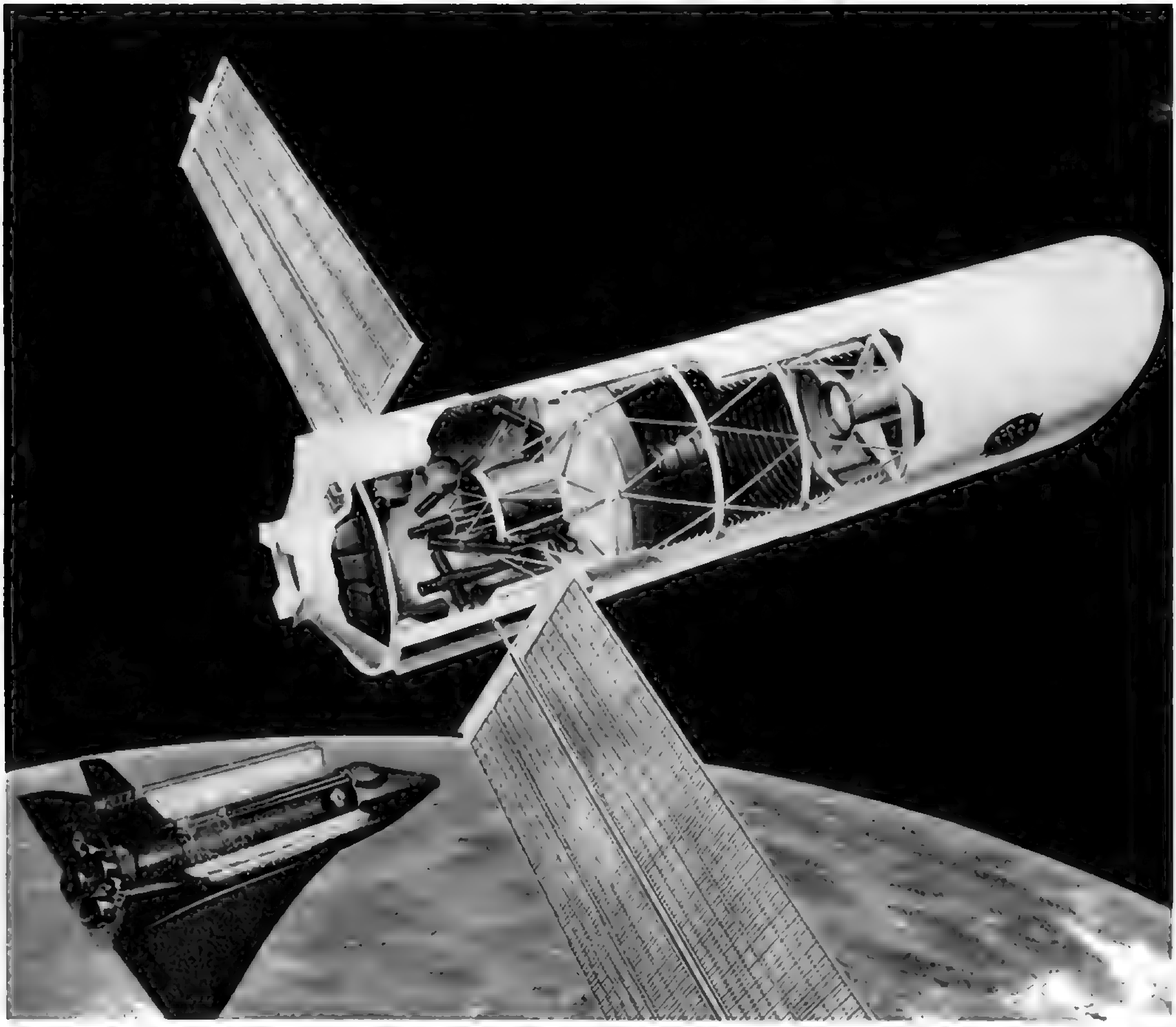
Huge new orbiting telescope will bare more secrets of the universe
By Wernher von Braun

Swimsuit sailboats let you get into sailing for under $1000

PS car test: VW Rabbit vs. Vega, Pinto, Gremlin

Flying clubs get you off the ground at a down-to-earth price

Huge new orbiting telescope will bare more secrets of the heavens



Large Space Telescope, to be the most powerful in the world, will circle earth in 380-mile-high orbit after launch from Space Shuttle, seen at the lower left of the drawing. Crewless, and operated by ground command, the LST will be unique in being recoverable in orbit—either for minor servicing by astronauts in the Shuttle's cargo bay, or for return to earth and subsequent relaunching after a major overhaul or refitting with more-advanced gear. This view, partly cut away to show arrangement of telescope mirrors and instruments, is a Lockheed artist's conception of the LST.

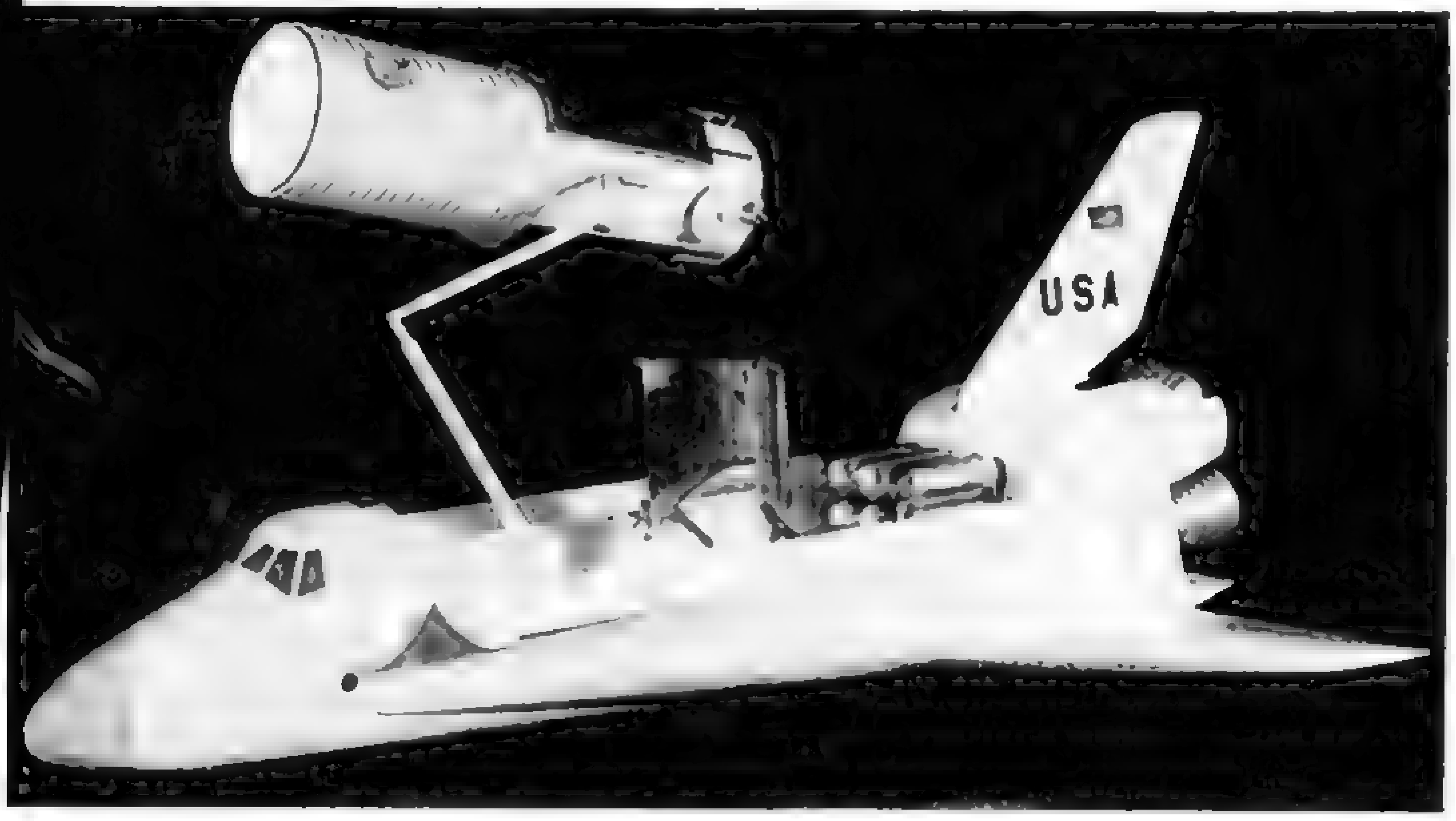
Plans are taking shape for the world's most powerful eye (put in the sky by our coming Space Shuttle) for viewing stars and planets

By WERNHER von BRAUN
PS Consulting Editor, Space

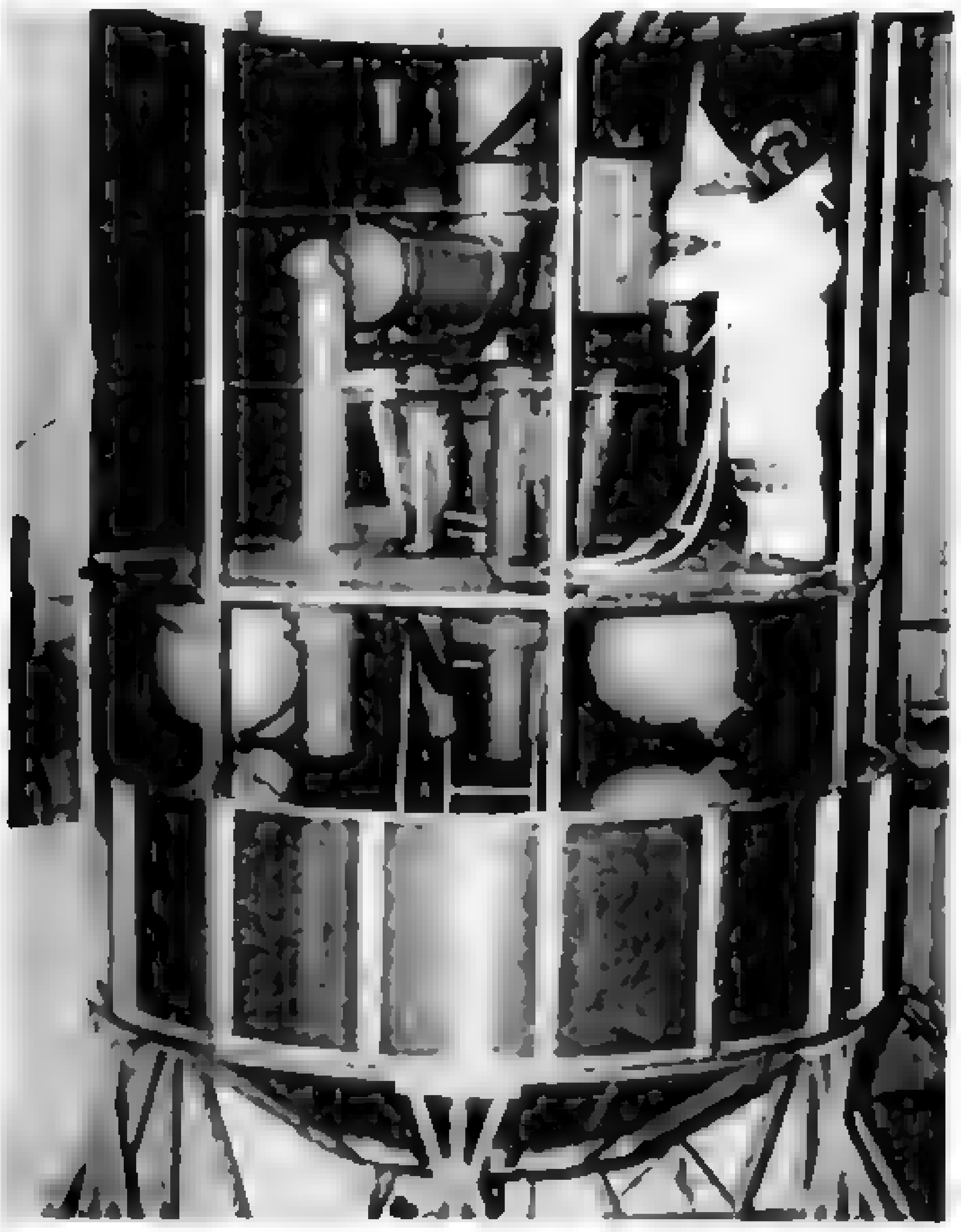
In 1981 or 1982, NASA will put in service the mightiest astronomical telescope in the world. Its Large Space Telescope (LST) will outperform the greatest telescopes on the surface of the earth—our 200-inch giant on Mt. Palomar in California, and even the huge new six-meter (236-inch) reflecting telescope in the Caucasus Mountains of the Soviet Union.

The LST won't need an optical system of their grand scale to do so, because of the incomparable advantages of operating in the vacuum of space. Orbiting 380 miles above the earth, it will not only be able to view celestial objects by rays that cannot penetrate the atmosphere. In addition, its pictures by visible and invisible wavelengths of light will be free of fuzziness from imperfect viewing—caused by refraction, or bending, of rays passing through variously heated regions of the earth's turbulent air. (The twinkling of stars strikingly demonstrates this effect to the naked eye.)

For a spaceborne observatory, however, the 10-ton LST will be of record dimensions. It will have a reflecting telescope with a main mirror 1.8 to 3 meters (70 to 118 inches) in diameter—at least twice the size of the largest ever orbited before, the 0.81-meter (32-inch) one carried aloft in 1972 by OAO-3—our Orbiting Astronomical Observatory named Copernicus.



Something new in space, snatching back a telescope from orbit, is pictured by Boeing models. Jointed arm draws LST into Space Shuttle's cargo bay.



Servicing recaptured telescope in orbit is practiced by space-suited technician in full-scale mockup of LST's aft section at Lockheed plant. Work will probably take place in Shuttle cargo bay.

Astronaut in mockup holds one of LST's high-resolution cameras, in close-up view of one trial servicing operation. If a key component like this should fail, he could replace it with another.

The LST's tenfold improvement in resolution over existing telescopes, enough to enable it to distinguish two headlights of a car as far away as from Washington to Moscow, for the first time will open the possibility of seeing earthlike planets orbiting the nearest fixed stars. The existence of such trans-solar planets, a key clue to the chances of intelligent life beyond our solar system, has been indirectly confirmed in recent years by their telltale perturbation of the motions of remote suns like Barnard's star. Actually viewing the planets would be a sensational triumph for astronomy.

Given a 2.4-meter mirror, just midway in the possible-size range, the LST will be able to observe stars 50 times fainter, and seven times farther away, than can be seen by the best telescopes today—assuming, as expected, that it can be precisely trained on them for exposures up to 30 or 40 hours. What excites astronomers most is the hope of seeing all the way to the outermost rim of the observable universe, and looking at galaxies so distant that their light started on its way to us billions of years ago.

Many cosmologists believe that the entire universe was created in a catacylsmic explosion, which they call the Big Bang, some 15 billion years ago—and that it was pitch black and filled with nothing but dark clouds of dust from the explosion for billions of years following. Only when gravity pulled this dust together did stars form, and "light up" when they reached a mass large enough to start nuclear-fusion reactions in their centers. The LST may give us our first look at such just-lit stars, and shed new light on the story of creation.

There will be decidedly practical uses for the LST nearer home in our own solar system. Its cameras can maintain a constant watch of weather changes on other planets such as Mars and Venus. Studying their meteorology should help us understand our own global weather patterns. It might also foretell earth's future fate from observing changes like the buildup in our atmosphere of carbon dioxide since 1900, or a marked chilling trend that began on earth about 1950.

Besides these predictable uses of

Continued

Big six-foot trial mirror for LST, made by Itek Corp., awaits coating with reflective aluminum. Pending this finishing touch it is transparent and reveals its honeycomb-type structure. Coring out unneeded portions at its back saves about 20 percent of weight of a so disk without impairing optical cha teristics and strength.

the LST, there will almost certainly be surprise discoveries, quite possibly so important to us that we'd like to re-equip the LST especially to study them further. For the first time this will be possible.

Recoverable from orbit

Launched into orbit by our coming Space Shuttle, the LST will be a crewless observatory, operated by remote command from the earth. But it will be our first *retrievable* space observatory, which can be visited and taken aboard by the same Space Shuttle or another. Minor servicing in orbit by spacesuited astronauts is feasible. A major refitting, or overhaul, can be accomplished by the LST's return to earth and subsequent relaunching—planned about every 2½ years during the LST's 15-year life.

The LST is to be one of the first payloads for the Space Shuttle. So that the Shuttle can climb to the LST's high orbit it will have an extra set of storable-propellant tanks for its Orbital Maneuvering System (which is distinct from the main hydrogen-oxygen engines). The Shuttle will carry the added tanks in the after part of its cargo bay, just behind the LST itself. The beefed-up Orbital Maneuvering System will propel the Shuttle from a low 100-mile-high orbit to that of the LST—and later, back to the lower orbit before deceleration for reentry in the atmosphere.

Overall the LST will measure something like 12.5 meters (41 feet) long—or 20 meters (65 feet) with a sunshade extended—and 3.7 meters (12 feet) in diameter, not counting solar-power panels deployed in orbit. While these figures are specifically for the 3-meter-mirror version, they probably would not be greatly revised if a smaller mirror should be chosen.

The LST will be an all-purpose observatory, instrumented to exploit all the possibilities of a huge space telescope—in contrast to its predecessor Copernicus, limited to ultraviolet spectrometry and X-ray observations. Through an aperture at the center of the LST's large mirror, its telescope beam will reach a far more varied array of interchangeable instruments.

TV pictures to earth

Direct images of stars, nebulas, galaxies, planets, and comets—both by visible light and invisible rays —will be radioed to earth by television cameras. In addition, the LST will wield spectrographs and photometers of a wide range of designs, for key astronomical data.

LST cameras will use no photo film nor need it. The all-electronic orbit-to-ground TV recording system will be far more sensitive. It will also excel the limited storage capacity of film emulsions during prolonged exposures.

The LST's price tag

So ambitious an orbiting observatory as the LST will certainly not be cheap. NASA's four preceding OAO's—of which two, including Copernicus, were successful—cost a total $363 million. "Ballpark" NASA estimates run close to this for a single LST with a meter mirror.

Current government budget pr lems have lately raised seri doubts about getting the fund for such an expensive LST. Hen trade-off studies now are taking hard look at paring the cost w a smaller telescope-mirror diamet of 2.4 meters (94 inches), or of 1 meters (70 inches). A mirror this reduced range should st make the LST superior to all eart telescopes in high resolution—th gauge of a telescope's useful magni fying power.

The larger (and more costly mirror sizes would gather mor light—much as a big-eyed, ultra fast camera lens does—and similarly minimize exposure time; which, for some of the farthest and faintest stars, might otherwise become prohibitively long. But even a two-meter mirror would multiply by a whopping 30 times the fraction of the universe that can now be observed with precision.

Thus there seems room for debate and possible compromise. A preview of leading scientific opinion is a recent announcement by the Space Science Board of the National Research Council that it would settle for, and recommends, a mirror size as large as two meters (79 inches).

It's comforting to know that the fantastically promising LST won't be fatally disabled by any malfunction in space (as two OAO's were). Uniquely, it can be retrieved from its orbit to be repaired, then put back into operation.

This is the way the **LST's scope** will work...

To tell the dramatic highlights of the LST story, the preceding account has skipped these technological details worth noting:

Telescope: Reflector of Cassegrain type—a standard one often employed on earth and in space.

Large mirror: Material will be either fused silica, of ultra-low expansion; or a glass ceramic called Cer-Vit, introduced by Owens-Illinois [PS, Sept. '69]. Both offer near-zero expansion or contraction, to avert distortion by temperature changes as the LST's attitude varies with respect to the sun. The mirror's face will have an aluminum reflective coating.

Graphite-epoxy, also immune to thermal distortion, will serve instead of metal for a 6.7-meter (22-foot) metering truss that spaces the large and small mirrors at just the right distance for perfect focus.

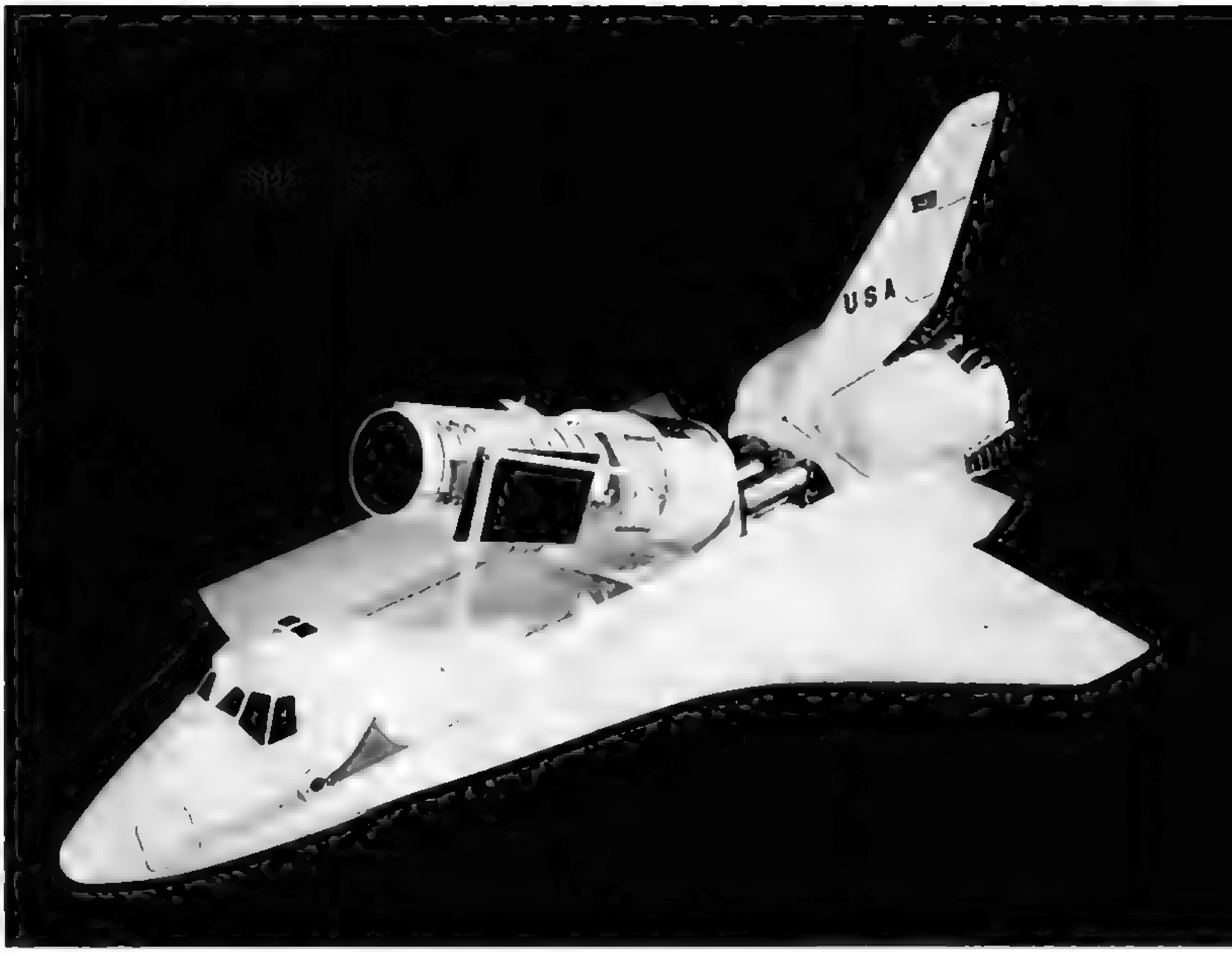
Instruments: In the instrument compartment behind the telescope, imaging cameras and other instruments can be used simultaneously or interchangeably. When several instruments are to be used at once, radio command from the ground selects which ones are to be activated, and the telescope beam will be split up for their respective use.

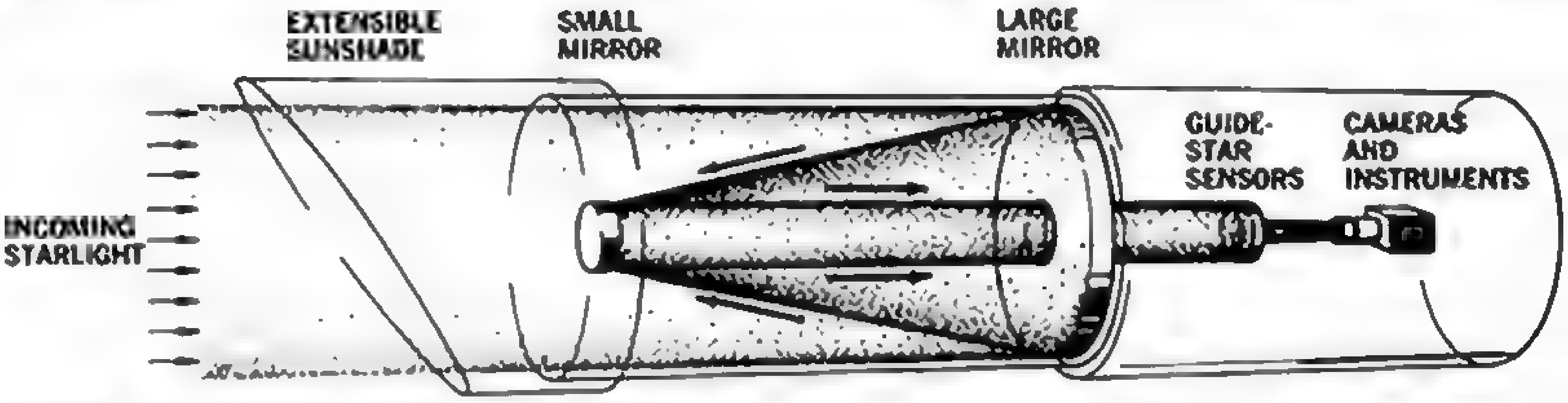
Cameras will have filters to select the visible or invisible wavelengths that are desired for image-forming observations.

For spectroscopic observations, available instruments will include spectrometers of varied types—some of high resolution for bright celestial objects and others, for faint-object spectrometry, with more-limited resolution. There will be photometers, too, with liquid-nitrogen or liquid-helium cooling for infrared photometry.

A substantial electronic capacity will provide for handling and storing large amounts of data and transmitting it to earth.

Aiming the LST: For reference, star sensors will lock onto a selected bright star near the desired target—perhaps another star, or a planet.





Design of reflecting telescope is compact Cassegrain type widely used in ground and space observatories. Large mirror collects starlight and small mirror beams it back through aperture at big one's center, as shown in cutaway view by Boeing artist. Photo at top, of Boeing model, shows LST being up-ended from horizontal to vertical, in preparation for its release in orbit.

An inertial-guidance gyro marks and remembers this initial position. It detects when the LST has carried out a command to swing away from the guide star to exactly the sky latitude (declination) and longitude (right ascension) of the target.

Three "control moment" gyros provide the actual muscle to turn the LST to its target. Gyros of this type were used with great success to point Skylab's array of solar telescopes.

Then, while the LST is circling the earth—which itself is moving through space—the attitude-controlling gyros hold the LST's aim steady as a rock on its target, peering at it for hours on end throughout a camera or spectrograph exposure that may take the greater part of two days.

Once the LST is on target, its specifications call for it to hold its aim steady with unprecedented precision: to within an angle of only 1/5000 of an arc second. (One arc second, which is 1/3600 of one degree, is about the angular size of Jupiter's orange moon Io as seen from Earth.) The LST's aim-holding accuracy will be comparable to a marksman holding a dime in his sights at the distance from Boston to Washington, D.C.

Orbit: The LST will circle the earth every 96.6 minutes. Its 380-mile orbit will be inclined to the equator by 28.8 degrees.

Power: Solar panels always facing the sun will supply electric power for gyros, instruments, and data-handling electronics. Two 2.4-meter (eight-foot) dish antennas on long booms receive radio commands, and transmit observations to a ground control center. For uninterrupted two-way communication with earth, the dishes will always be aimed at relay satellites in synchronous orbit, which in turn provide line-of-sight radio links to and from the ground.—*W. v. B.*

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Popular Science

The What's New magazine

NEW TURBO-ELECTRIC CAR

- Recharges on the run for long range
- Plugs in overnight for thrifty driving around town

Energy from space for use on earth
By Wernher von Braun

How the sun's heat can cool your home

25-PAGE SPECIAL SECTION
of home-improvement ideas to save heating dollars and perk up th
your house thi

...plus What's [illegible] r fact-filled features

Coming—

Energy from space

for use on earth?

Microwave beams point the way to solar-power stations in orbit—and satellites to relay energy around the globe

By WERNHER von BRAUN
PS Consulting Editor, Space

This summer, blazing lights on a hillside at Goldstone, Calif., were expected to signal the transmission of tens of kilowatts of electric power for a mile by a microwave beam. It would be the furthest step yet toward novel and imaginative proposals to supply earth dwellers with energy from space.

One such concept envisions an orbiting solar-power station that would beam energy to earth by microwaves. An alternate concept: a power-relay satellite that would deliver energy across continents or oceans from a solar or nuclear sta-

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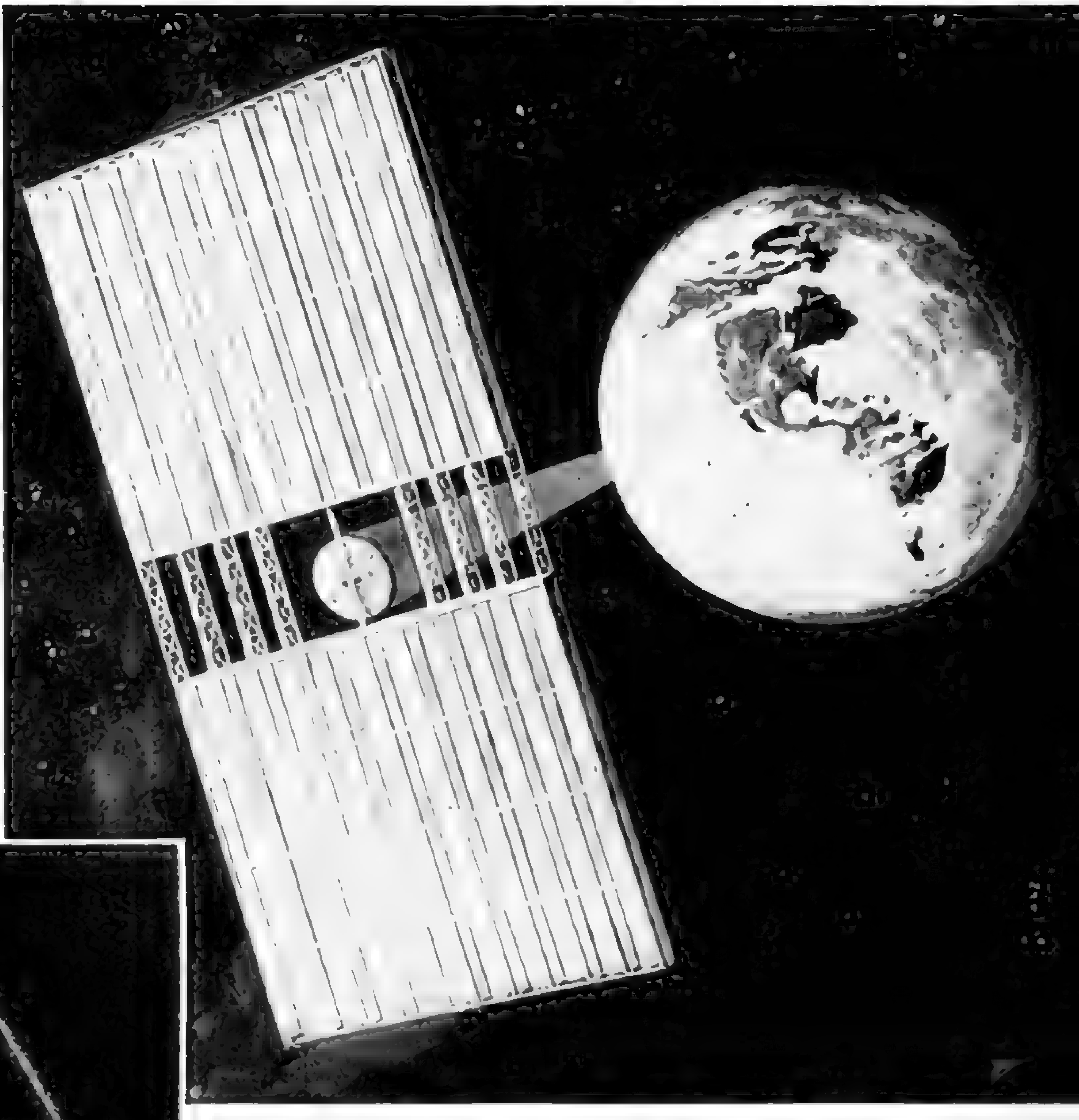
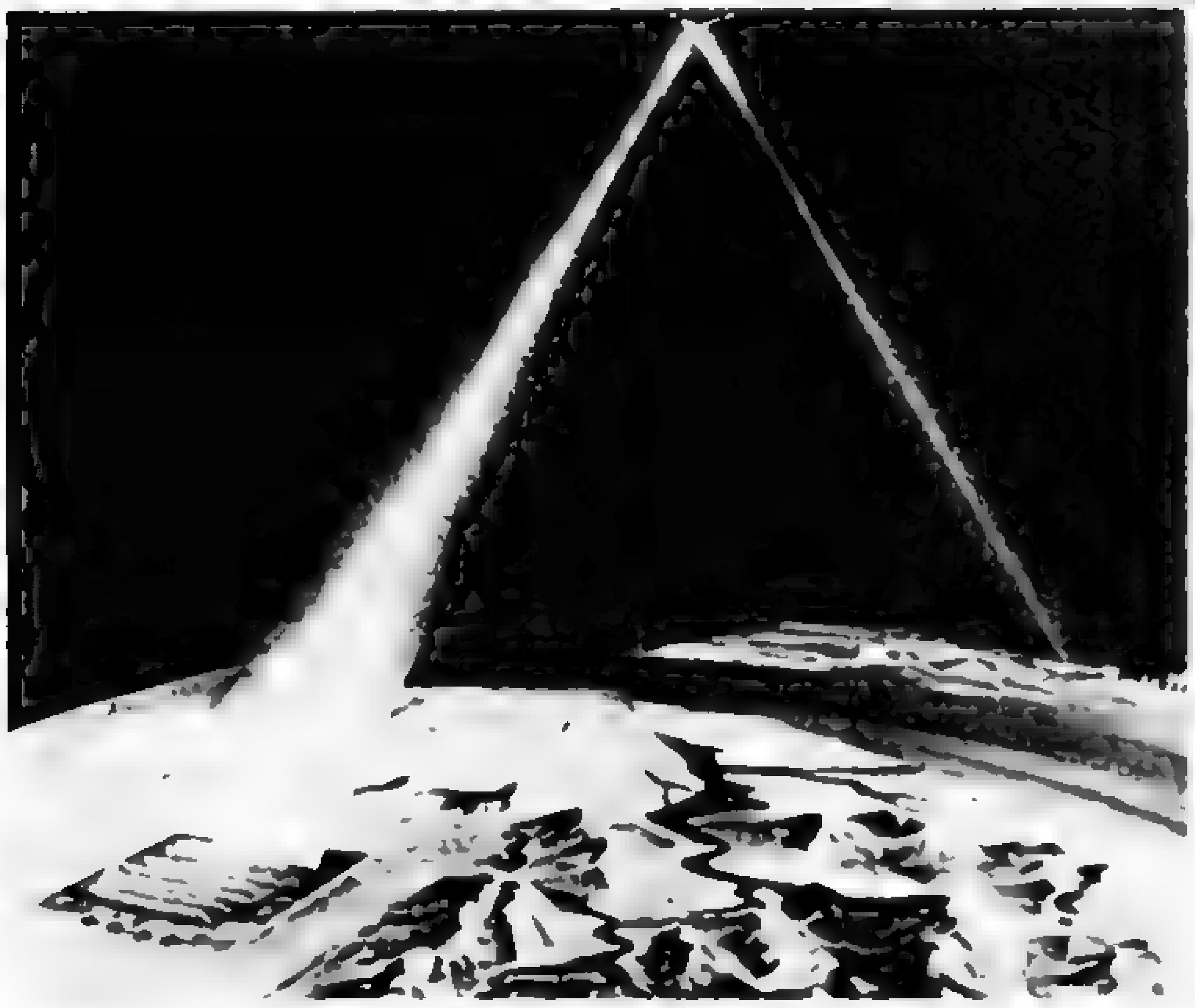




Gigantic solar-power satellite beaming energy to earth, proposed by Dr. Peter Glaser, is visualized in Grumman picture above from Arthur D. Little, Inc. It spans seven miles the longest way and would be assembled in geosynchronous orbit. Antenna between solar arrays transmits their electric power by microwave beam to a receiving station on earth. Alternate energy-via-space concept of Dr. Krafft Ehricke, pictured at left, uses satellite to relay power from a remote solar or nuclear plant on earth to a receiving station serving a populated region. Ground installation in foreground is transmitter of microwave-power beam.

tion at a remote place on earth.

Can we find help in space for the energy shortage? For the long haul the answer is an emphatic yes—though a close look at the two principal proposals so far shows that the haul may be long indeed.

Transmitting electric power from outer space to earth calls for starting with direct current provided, say, by a vast orbiting array of solar cells; converting it to a microwave beam; intercepting the beam with a receiving antenna on earth; and rectifying the energy to direct current for distribution to users. The rectifying units could be coupled to the receiving antenna, or built into it—a combination now called a rectenna.

The solar-power satellite

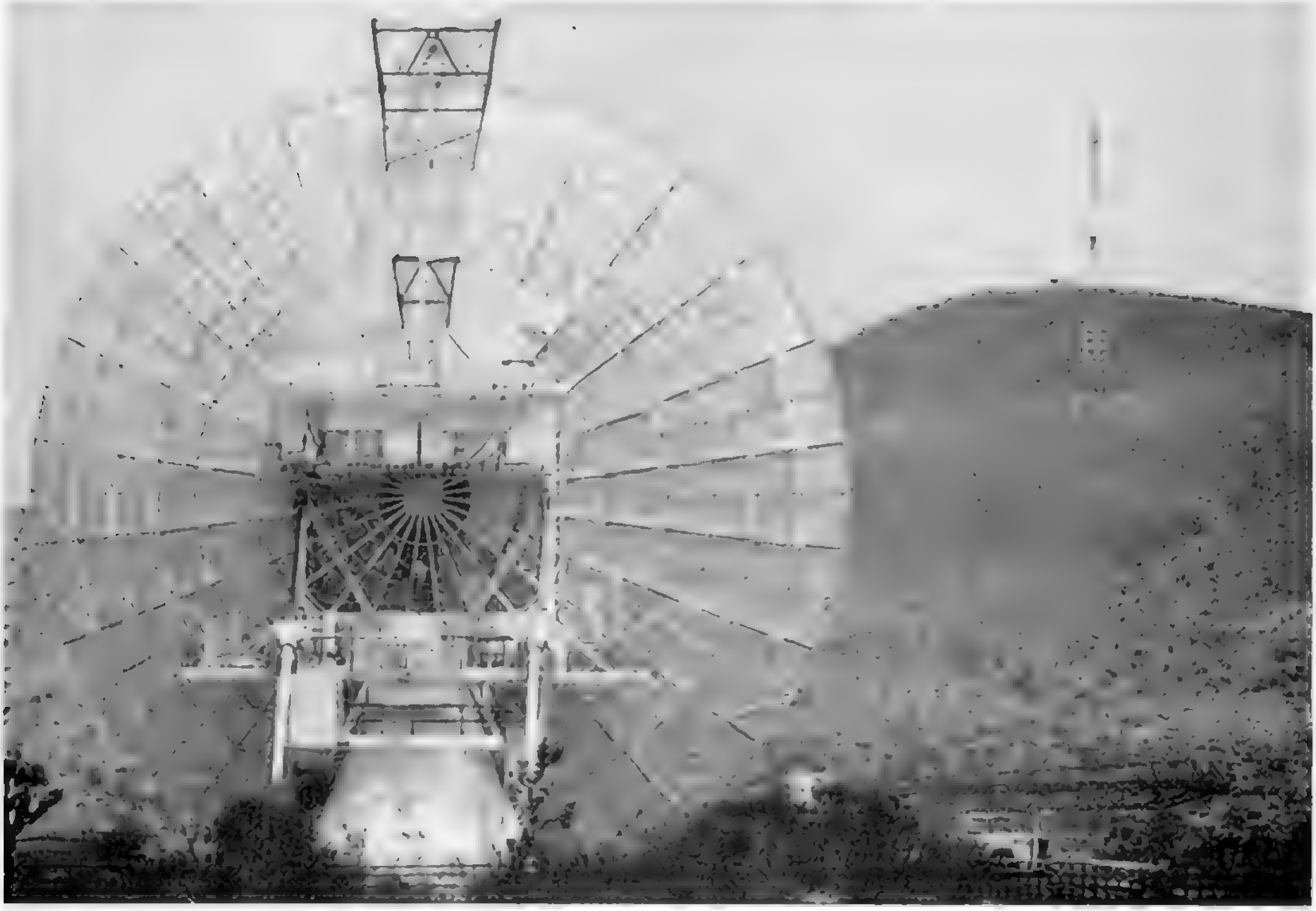
An orbiting solar-power station is the concept of Dr. Peter E. Glaser of Arthur D. Little, Inc., who heads a study team of specialists from his own company, Grumman, Raytheon, and Textron.

It would be placed in a geosynchronous orbit, 23,000 miles high, where it would hover over a fixed spot on earth, to deliver energy to a ground station. This concept has a lot of things going for it:

Outer space has no clouds, and no day-and-night cycle. The satellite's infall of sunshine would be interrupted only around the time of the equinoxes when the earth briefly shadowed it—for 72 minutes daily or less. The amount of energy it could collect would be limited only by the size of its solar arrays.

The proposed capacity of a Glas-

Hurling tens of kilowatts a mile without wires will be a step toward power from space



Big-scale demonstration of wireless power transmission by microwaves, scheduled for July and August 1975 by NASA's Jet Propulsion Laboratory and Raytheon, is readied at Goldstone, Calif. Dish antenna 85 feet in diameter (left foreground in photo above) will radiate 300 to 400 kilowatts toward a 12-by-14-foot receiver ("rectenna") a mile away on a hilltop tower, seen in right background of large photo and in close-up view at near right. It will recover sizable portion, expected to reach tens of kilowatts, of the beam. Pairs of high-intensity indicator lamps (far right) arranged in same pattern as rectenna's 17 elements, show which are energized as powerful beam sweeps across its target.

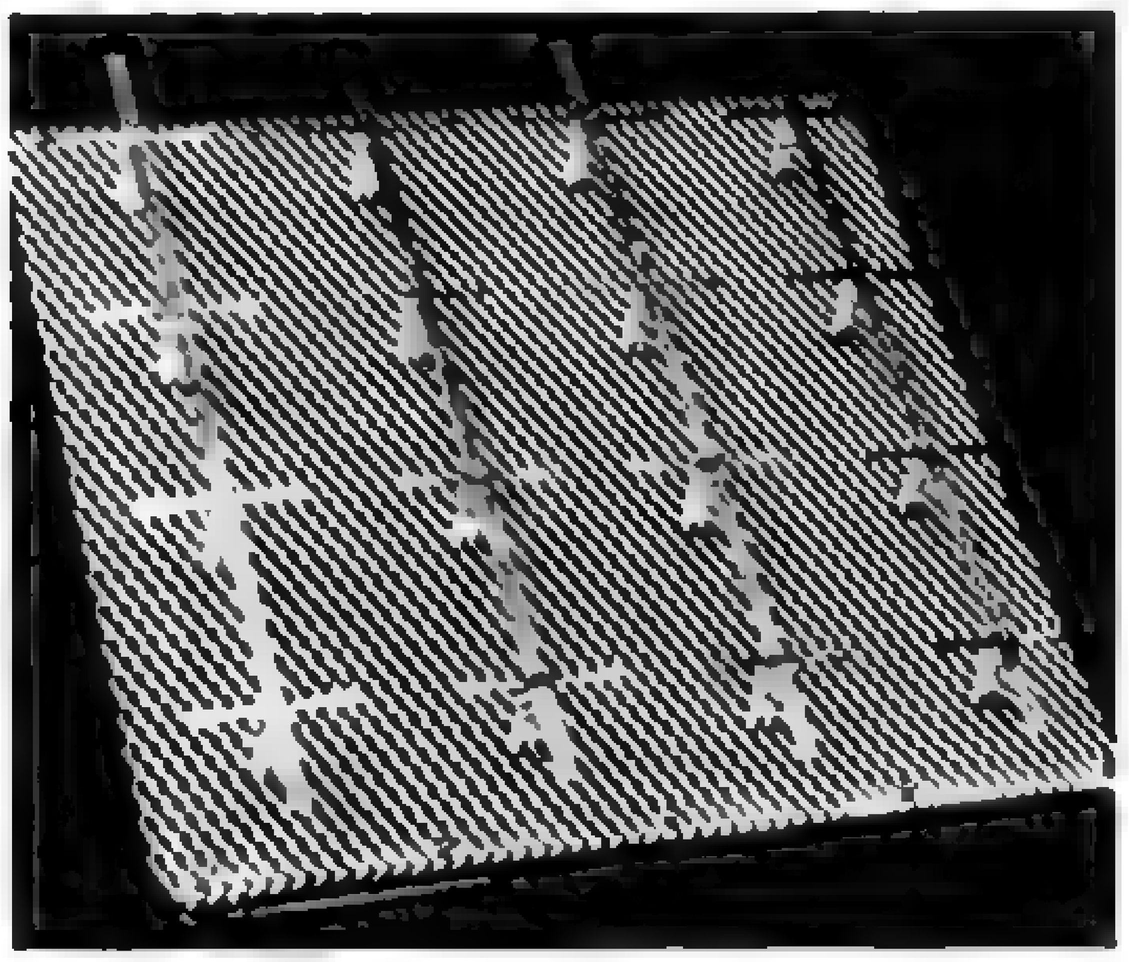
er solar-power satellite ranges from two million to 20 million kilowatts recoverable at the ground station. One satellite of 15 million kilowatts could supply the entire electric needs of a city the size of New York in the year 2000.

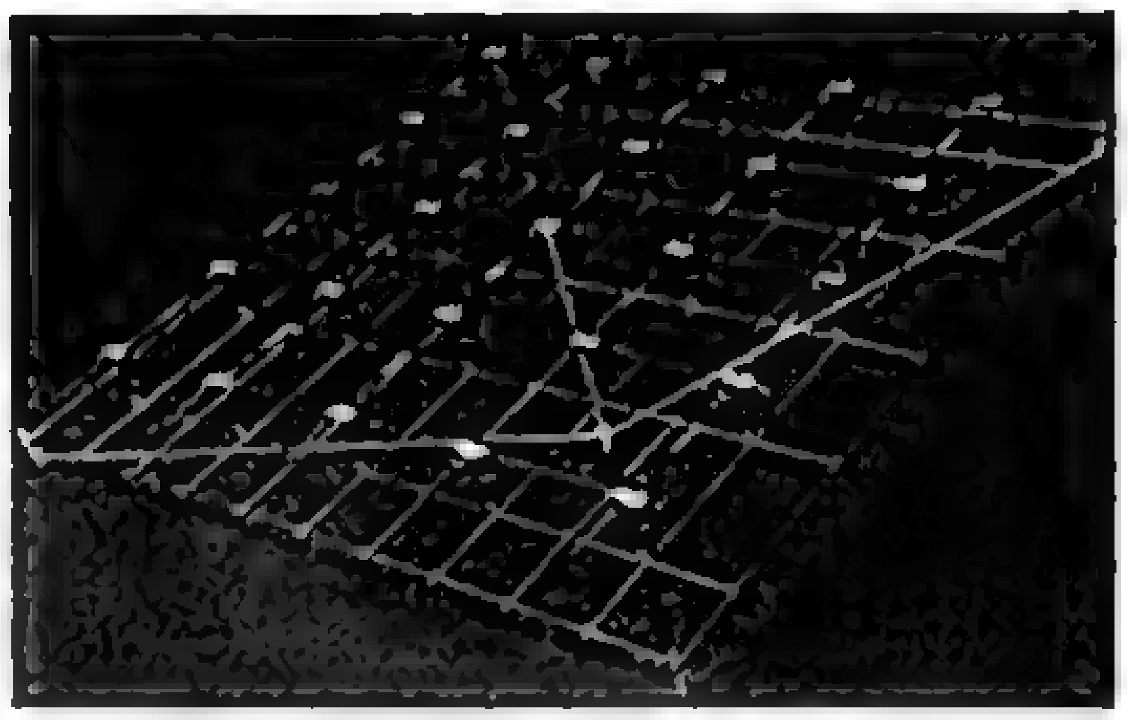
A design yielding five million kilowatts, illustrated on the opening page of this article, shows the satellite's gigantic size. It would measure almost 12 kilometers (about seven miles) the longest way. Strips studded with solar cells, like the ones that power present spacecraft but substantially cheaper, would have sunlight concentrated upon them by inclined mirror-like reflectors along each strip's borders.

Converted to microwaves by Amplitron microwave generators, the solar energy would be beamed earthward by a transmitting antenna with a diameter of one kilometer (about ⅝ of a mile), mounted between the two solar arrays. The frequency would be 3000 megahertz, which corresponds to a wavelength of 10 centimeters (four inches).

The terrestrial receiving antenna would be seven kilometers in diameter (4.3 miles), and the incoming energy would be converted to 40,000-volt DC to be fed into utility power grids.

Prototypes give views of hardware for energy from space





"Solar switchboard" above, into which Raytheon scientist William C. Brown is plugging a diode, is a model of rectifying unit at receiver that will turn microwaves back into usable direct current. Section of a receiving antenna for microwave power, upper right, illustrates an Arthur D. Little design. Another type, lower right, is especially designed for light weight by Raytheon. One-foot-square model in picture weighs only 20 grams and can deliver an output of 20 watts. A full-scale openwork antenna resembling this, supported flat on posts some distance above the ground, would absorb most of a microwave beam from space. Remaining radiation would be so low, cattle could safely graze beneath.

The power-relay satellite

Earth-to-earth power transmission via space is proposed by Dr. Krafft A. Ehricke, key planner for future space operations at Rockwell International and a space pioneer from way back. It, too, has its talking points:

A solar-power station on earth could be put in a sun-drenched spot, no matter how remote—say, the desert areas of the southwestern U.S. Or a giant nuclear station could be operated far from any populated region. In either case, a power-relay satellite in geosynchronous orbit could deliver the energy just where it was wanted.

Such a space system has the advantage that its largest and heaviest components stay on the ground, minimizing the cost of launching.

The power-relay satellite essentially would be a flat, square reflector of ultralight wire mesh, in sections, stretched like a painter's canvas on structural frames, and oriented to face the earth at geosynchronous altitude. For a relaying capacity of 10 million kilowatts, it would have an overall area of one square kilometer.

Like a mirror, this satellite would reflect a microwave beam from a ground transmitter on one side of it, back to a ground receiver on the other side. Both ground stations would be 10 kilometers, or about six miles long and wide. The giant scale is emphasized by the fact that the transmitter would employ no less than 1600 *million* corkscrew-shaped, "end-firing" antennas, each 3½ centimeters in diameter and 35 centimeters long. They would be mounted in rows on panels uniformly inclined, like slats of a huge venetian blind.

In both the Ehricke and Glaser concepts the key to safety at the receiving end will be to spread the incoming microwave beam over an antenna of great area, rather than to concentrate the power dangerously in a pinpoint beam.

Birds on the wing would be unharmed by exposure to the wide beam. Passengers in airplanes passing through it would have the added protection of the metal-enclosed cabin. On the ground, the receiving antenna itself would absorb so much of the beam's energy that it would be safe for people to walk beneath.

Launching the satellites

Power-from-space satellites would be carried aloft piece by piece, in coming Space Shuttles. (Glaser-type satellites—perhaps excepting a reduced-scale experimental one—may have to await a second-generation Shuttle that promises to cut transportation cost in half.)

Released in low earth orbit, the modules would climb to their final orbit under their own power. Even the minuscule thrust of electric ion engines could put them in a spiraling upward course to their station.

A team of space riggers would assemble the complete satellite by joining the modules. A small manned space station in geosynchronous orbit could serve these riggers as a base, Dr. Ehricke suggests. At least some of their tasks might be carried out by sophisticated free-flying robots called teleoperators, whose talented mechanical hands could be manipulated remotely under the guidance of television views from the robots [PS, Nov. '72].

Ultimately both Dr. Glaser and Dr. Ehricke foresee a sizable number of power-via-space satellites in orbit, forming a nationwide or worldwide net. But even one seems likely to be a long time coming.

The fantastic cost of a Glaser or Ehricke satellite appears to rule them out for the near future. It

[*Continued on page 125*]

[*Continued from page 67*]

can be estimated that a solar-power satellite of 10 million kilowatts would have the staggering cost of $23.4 billion, including cost of the ground receiver. This compares to the cost of our whole Apollo program. By far its biggest single item: the cost of the satellite's transportation to orbit and assembly there.

A power-relay satellite system of equal capacity comes off better, but still totals an estimated $5.03 billion, including the terrestrial power plant and microwave transmitter and receiver. Ground installations make up the bulk of it.

In decades to come, even figures like these will look less visionary, as our dwindling supplies of conventional clean fuels boost their price sky-high. In contrast, solar-energy space or ground systems will have no fuel bill at all for their 30-year lifetime. Except for maintenance, their first cost will be their last.

Moreover, the art of transmitting power by microwaves is still in its infancy. Its practical application dates from as recently as 1964, when an experimental model of a microwave-powered helicopter rose to 50-foot height in a Raytheon demonstration [PS Picture News, PS, Feb. '65]. Possible new breakthroughs in microwave technology could make power-from-space concepts more feasible.

Obviously NASA sees it none too soon to invest in preliminary work toward power via space, right now. NASA-funded studies have already led to prototypes of the basic hardware (see photos). Laboratory-scale experiments for NASA's Office of Applications have lately been climaxed by Raytheon at Waltham, Mass., with the transmission of 495 watts of power by microwave at 54-percent efficiency, DC to DC [Science Newsfront, PS, July]. This represents a threefold increase in microwave-power efficiency in the past decade

Major-scale trial next

Being readied at this writing was a dramatically big-scale outdoor demonstration of microwave-power transmission at Goldstone, Calif., by a Jet Propulsion Laboratory-Raytheon team. Trials were scheduled for July and August.

It aimed to beam tens of kilowatts of power from a 26-meter (85-foot) dish antenna to a rectenna-type receiver on a hilltop a mile away. Because of the receiver's limited size it would recover only a fraction, but a most respectable portion, of the 300 to 400 kilowatts to be radiated by the big dish. High-intensity lamps connected to the rectenna would show from afar when the invisible microwave beam was trained to cover it completely.

This is the "wireless power," a dream of the earlier 1900's, that has now become reality. Whether it will eventually lead to the Glaser orbiting solar-power station, the Ehricke power-relay satellite, or some other power-from-space plan still to come, the future will tell. PS

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A Shuttle-borne workshop for men and women scientists in orbit—

Spacelab

Orbital laboratory built in Europe will slash cost of seven-to-30-day cruises in space—by experts with finest of experimental gear

By WERNHER von BRAUN
PS Consulting Editor, Space

By this year's end a working model of Spacelab, called the most important payload planned for our coming Space Shuttle, is due to be finished by the European Space Agency (ESA)—complete with electrical, electronic, and other subsystems. Preceding work already gives a revealing preview of what the Spacelab, Western Europe's \$300-to-\$400-million contribution to our future manned-space-flight program, will be like.

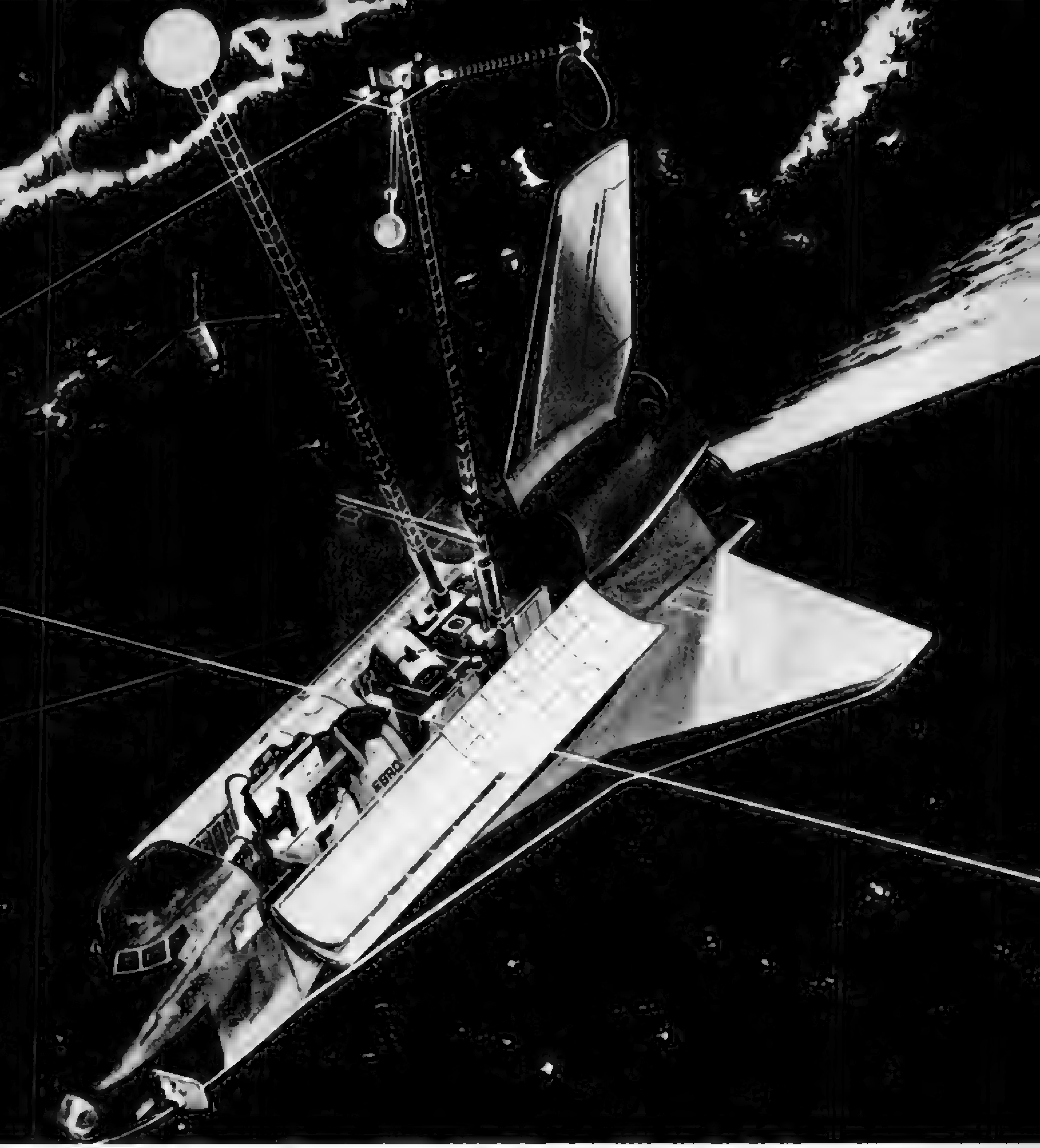
Beginning in 1980, when U.S. manned space missions will have resumed with the reusable Space Shuttle, made-in-Europe Spacelabs in its cargo bay will offer Americans and Europeans a golden opportunity for a week to a month of scientific research in orbit, with ideal equipment and in shirtsleeve comfort.

You won't need to be a qualified astronaut to work in a Spacelab. There will still be astronauts in the Shuttle's cockpit, to be sure. But the Shuttle's comparatively gentle ride aloft and back (only three g's of force instead of Apollo's six g's) will enable any scientist, engineer, or technician healthy enough to ride an airplane to join a Spacelab's crew.

A Shuttle-borne Spacelab, pictured in action by NASA artist, observes an aurora close-up. It can make artificial auroras by bombarding vicinity with high-voltage particle accelerators mounted at after end of pallet. This version of Spacelab has AMPS (Atmospheric, Magnetospheric, and Plasmas in Space) payload to test effects of prodding space with varied array of science gear.

Spacelab mockup shows pressurized lab, about 13 feet in diameter inside, and instrument pallet aft. Duplicate modules can extend lab or pallet. Conical caps will cover wide doorways at ends; tunnel from Shuttle enters forward cap.

Not an independent spacecraft, Spacelab will remain firmly attached to the cargo bay of a Shuttle Orbiter throughout a flight. Its crew will go aloft and return to earth as passengers in the Shuttle. In earth orbit at a height of about 400 kilometers (250 miles), the cargo-bay doors open, and the un-



covered Spacelab will be ready for its crew to occupy and use.

A Spacelab consists of one or both of two basic types of modules:

• *A pressurized lab* has a roomy inside diameter of about four meters (13 feet); a typical two-segment one is some 6.9 meters (22½ feet) long, overall. Side walls will be lined with racks of experimental apparatus (interchangeable to suit each mission), with working spaces left for tests. The lab will have windows at top and aft; and an airlock and hatch for EVA (extravehicular activity, popularly called spacewalking).

• *A trough-shaped pallet* or deck, made up of modules with a length of 2.9 meters (9½ feet), will mount instruments that must be exposed to the vacuum of space. Visible from the aft lab window, the pallet instruments can be controlled from the lab, the Shuttle, or remotely from earth; and can be visited if necessary by EVA with the use of a spacesuit.

Either the lab or the instrument pallet may be lengthened simply by adding duplicate modules, to meet different missions' needs. Spacelab's design can be further varied by omitting one of the two basic kinds of modules. Some

Continued

Spacelab missions will have a pressurized lab only, which could take up most of the Shuttle cargo bay's length. Other missions will have an extended instrument pallet, only.

But the most favored Spacelab design in numbers, among 276 Spacelab missions anticipated in 1980-1991, will be the attractively versatile lab-and-pallet combination; and its West German builder is giving priority to this kind.

A NASA-added tunnel enables a Spacelab crew to enter the lab from the Shuttle, and return to Shuttle living quarters for meals and for sleeping. Weightless in orbit, crew members will easily float through the tunnel, and to any station from top to bottom of the lab.

By way of a utilities duct from the Shuttle, Spacelab is provided with an earthlike cabin atmosphere, electric lighting and power for instruments, and an intercom link with the Shuttle.

Who's aboard Spacelab?

Spacelab crews will number from one to four members. For the first time they can be chosen solely for science talent, and regardless of sex. Many crews are expected to include women as well as men. For some missions, an all-female crew is a possibility. A team of four women aspirants recently spent five days at Marshall Space Flight Center, rehearsing a proposed series of 11 tests in materials science.

Fashions for Spacelabbers may depart from the conventionalized symbols in the sketch below. Jumpsuit-type togs may prove more practical in zero gravity, both for men and women.

Spacelab experiments will explore fields as varied as physics, astronomy, zero-gravity materials processing, life sciences, meteorology, earth-resources surveys, and monitoring air and water pollution.

Unlike a passive probe, one dramatic mission will actively stimulate space with such potent gear as high-voltage accelerators capable of making artificial auroras, and a high-power radio antenna 305 meters (1000 feet) long, seen extending crosswise in view on preceding page. Better understanding of radio blackouts, and how solar radiation affects our weather, may result. An attack on a Van Allen radiation belt, with light gases released from canisters, will test if it can be temporarily dispersed.

What amounts to a luxury space cruise for experimenters will end with the Shuttle's smooth touchdown like a plane on a spaceport runway.

Although a Spacelab crew will be non-astronauts, any expert help they might need will be no farther away than the opposite end of the Spacelab-Shuttle intercom. In the Shuttle crew will be a science astronaut called the Mission Specialist, who presumably will have thoroughly studied the script of their particular mission. He would be well qualified to don a spacesuit and do any astronaut-type chores for them such as EVA's—say, to reload photo film in a pallet instrument, or perform other routine tasks of servicing their sophisticated science gear on Spacelab's open "back porch."

In the Shuttle cockpit itself, the Mission Specialist could be expected to supervise special flight maneuvers for certain Spacelab missions—say, to launch and recover a free-flying subsatellite aboard some Spacelabs, or simply to have the Shuttle flown upside down to give an earth-resources mission a downward-looking view.

Bargain-cost space science

Especially attractive to thrifty taxpayers will be how much further Spacelabs will make our space dollars go. Since all elements of Space Shuttles are reusable (except an empty propellant tank), they should cut the cost of transporting payloads into low earth orbit to about 15 to 20 percent of the expense with today's expendable multistage rockets [PS, Nov. '74]. But that is really only half the story.

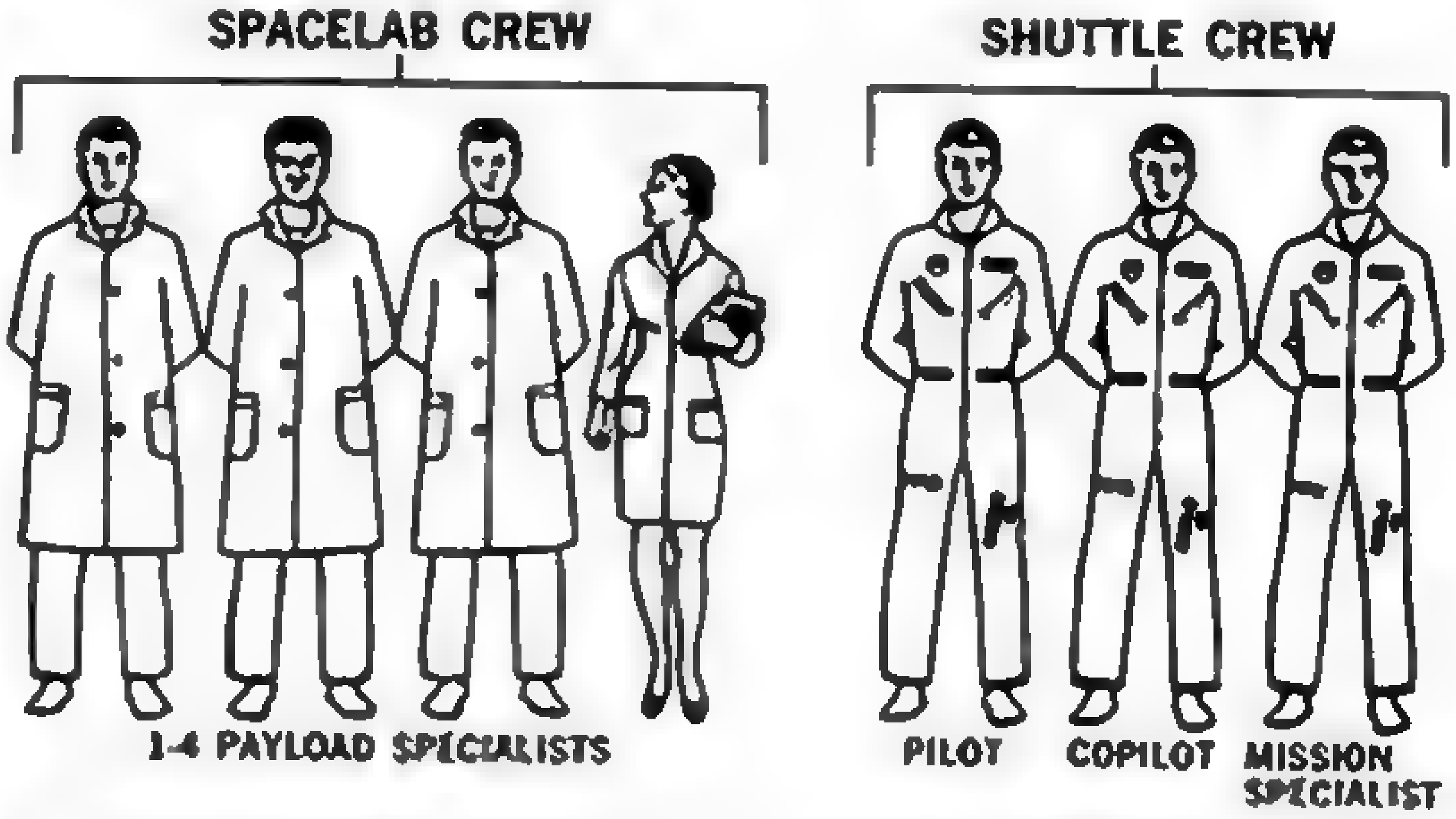
Vast added savings come from the ability to bring back expensive scientific equipment intact, so that it can be used over again.

Spacelab scientific gear not immediately used again will go to a growing "pool" of instruments where future crews may well find the very ones they need, right off the shelf, instead of needing costly new ones made to order.

Recurring opportunities for Spacelab flights will allow a mission plagued by a key instrument's misbehavior to be repeated once the trouble is fixed. That contrasts with the present unforgiving situation where, as a wisecrack puts it, "a 99.9-percent-perfect space mission might be identical with a complete mission failure."

Finally, the Shuttle will put an end to costly naval operations to fish returning space crews from the sea—that orchestrated pageant of fast carriers, helicopters, and teams of skilled frogmen, dramatic but needlessly extravagant by coming standards.

The story behind Spacelab—like that of the successful US-USSR



Spacelab and Shuttle crews are symbolized by NASA sketches above. Members of Spacelab science teams need not be trained astronauts, and many will include women. Some Spacelab missions may have an all-female crew like group at left, visiting Marshall Space Flight Center to practice a proposed series of 11 experiments in materials science.

and details of its design

manned space mission last July—is a happy one of international co-operation, with mutual benefits.

Airborne astronomy, meteorology, geophysics, and earth-resource surveys had been carried on for years by NASA in a Learjet, a Convair 990, and a Lockheed C-141. Results convinced NASA that much could be gained, and much money saved, if the "lifestyle" of these airplane operations could be moved into space. Our new reusable Shuttle could provide the needed transportation. But still missing was an equally reusable and versatile multipurpose laboratory that would fit into the Shuttle Orbiter's cavernous cargo bay—18.3 meters (60 feet) long and 4.6 meters (15 feet) in diameter.

How Spacelab came about

The year 1972 found NASA in the predicament that it had barely enough funds to develop the Space Shuttle itself, and not a dime to spare to spend on the desired lab. Luckily the time was opportune to invite Western Europe to assume the cost of developing the lab, and share the privilege of its use.

The Europeans had long been eager for a more active role in space—a proven "cutting edge" for scientific and technological progress. But ESA's predecessor, the European Space Research Organization (ESRO), was then having all kinds of problems with an ambitious project of its own—to develop a large multi-stage launch rocket called *Europa*. Each rocket stage was the responsibility of a different country. Fitting together the pieces was taking an inordinate amount of time, and *Europa* was disappointingly slow to materialize. Moreover, America's coming reusable Space Shuttle threatened to make a "throwaway" rocket like *Europa* obsolete before it was completed, for peaceful space missions at least.

ESRO made the wise and logical decision, all things considered, to revamp its priorities, and accepted NASA's invitation to develop the lab for the Shuttle. As a beginning it coined the catchy name, Spacelab. Avoiding its *Europa* mistake of failing to provide strong central management, it would put one prime contractor in overall charge of developing the Spacelab.

West Germany's contribution of 54.1 percent of the program's cost was by far the largest, and so, un-

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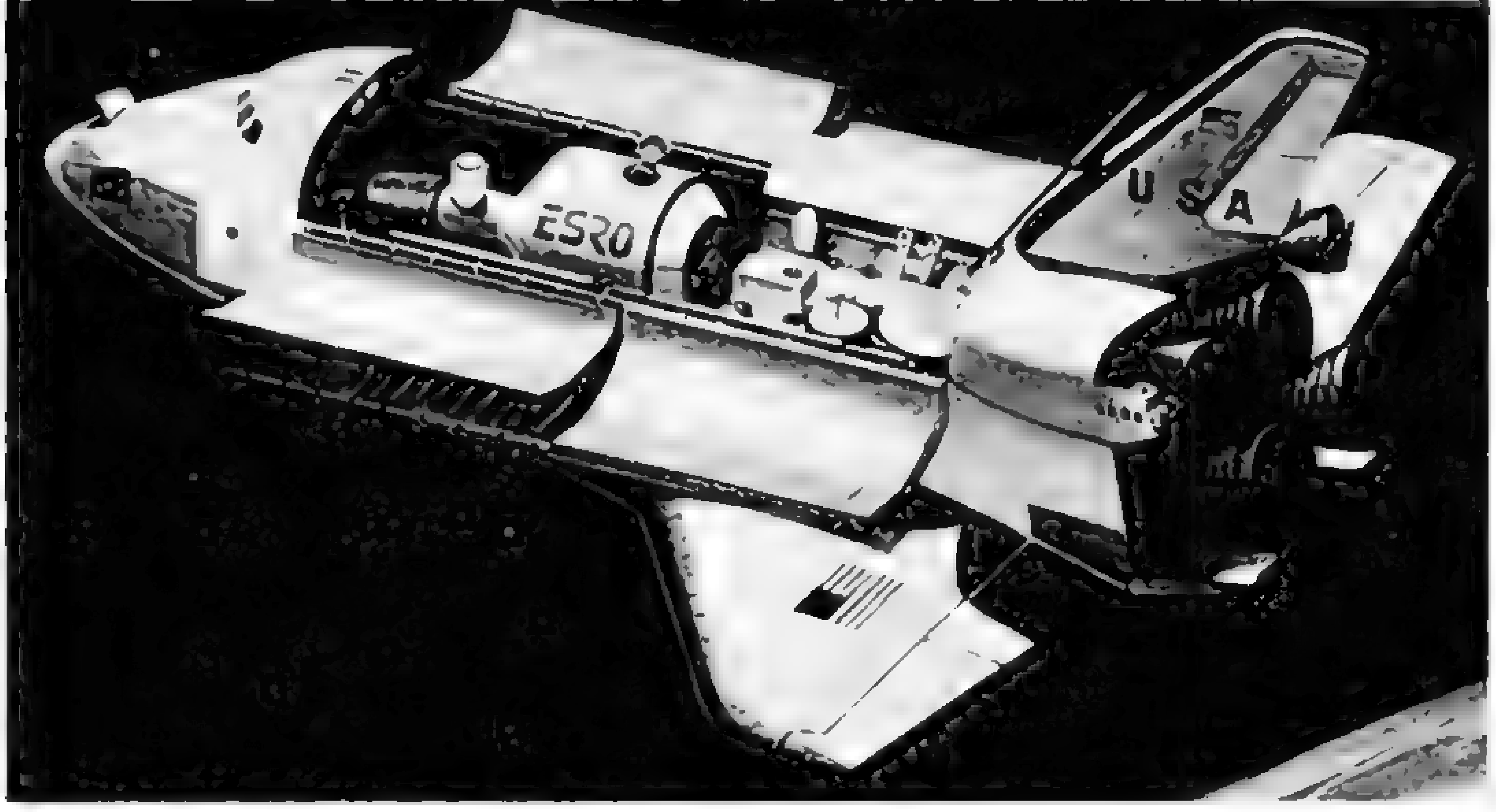
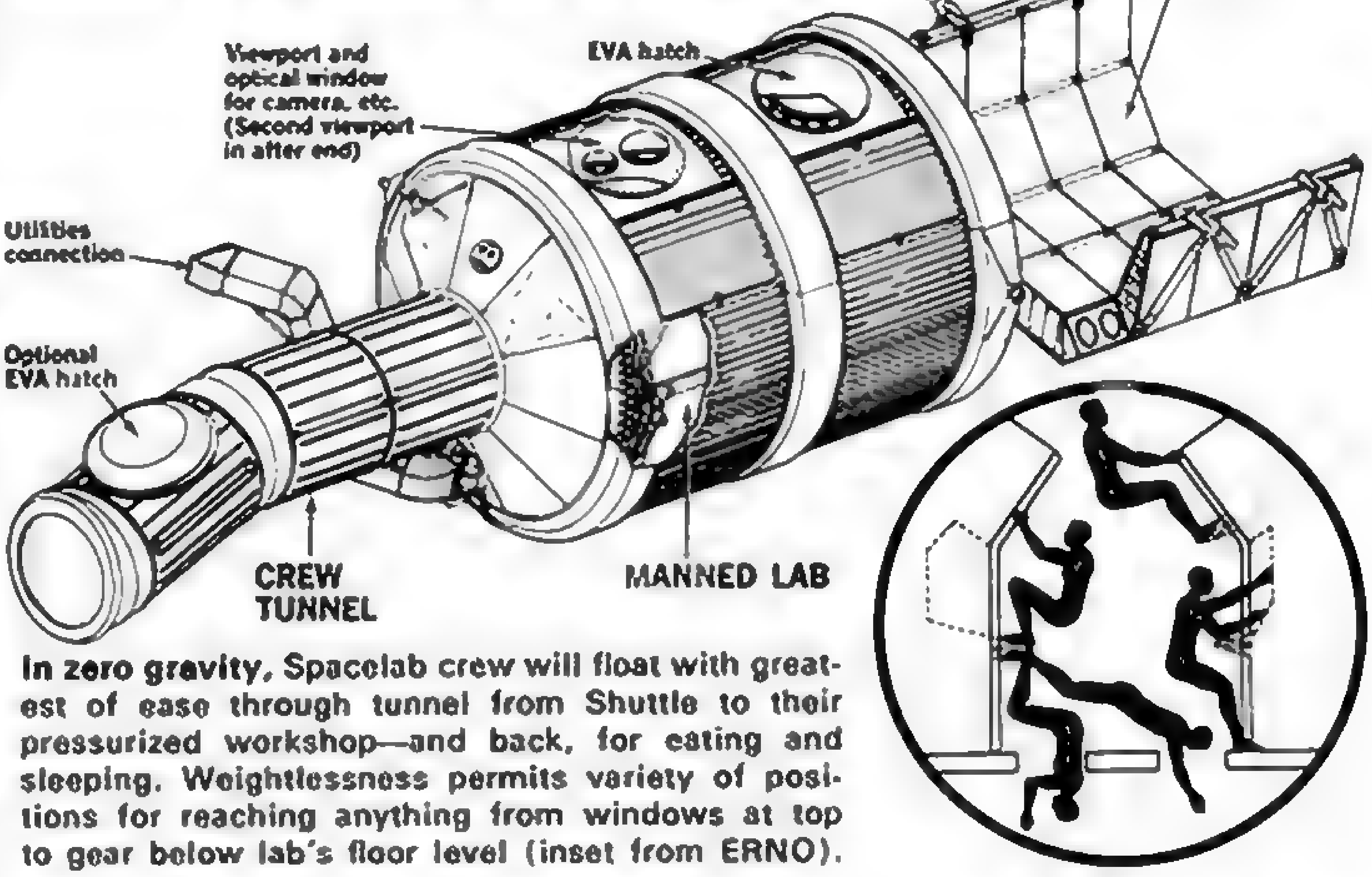


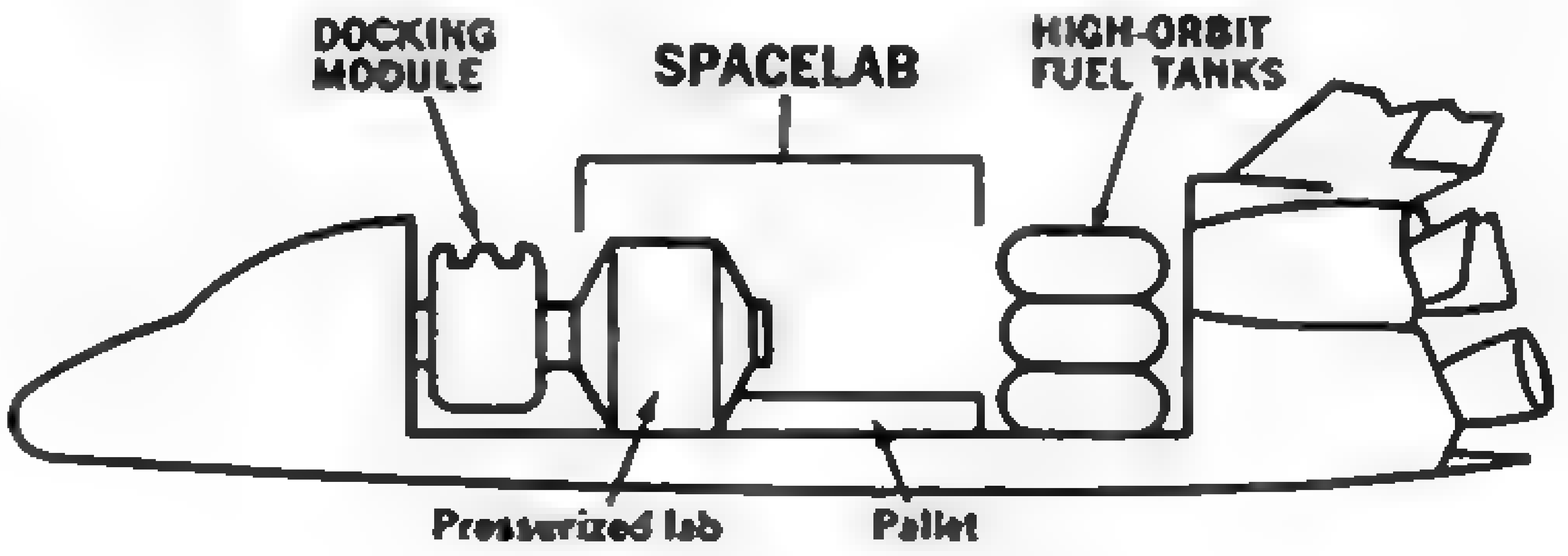
Spacelabs' outward appearance varies widely (compare this one and preceding AMPS version), due to different science gear and arrangement of modules—but all have same basic modules.

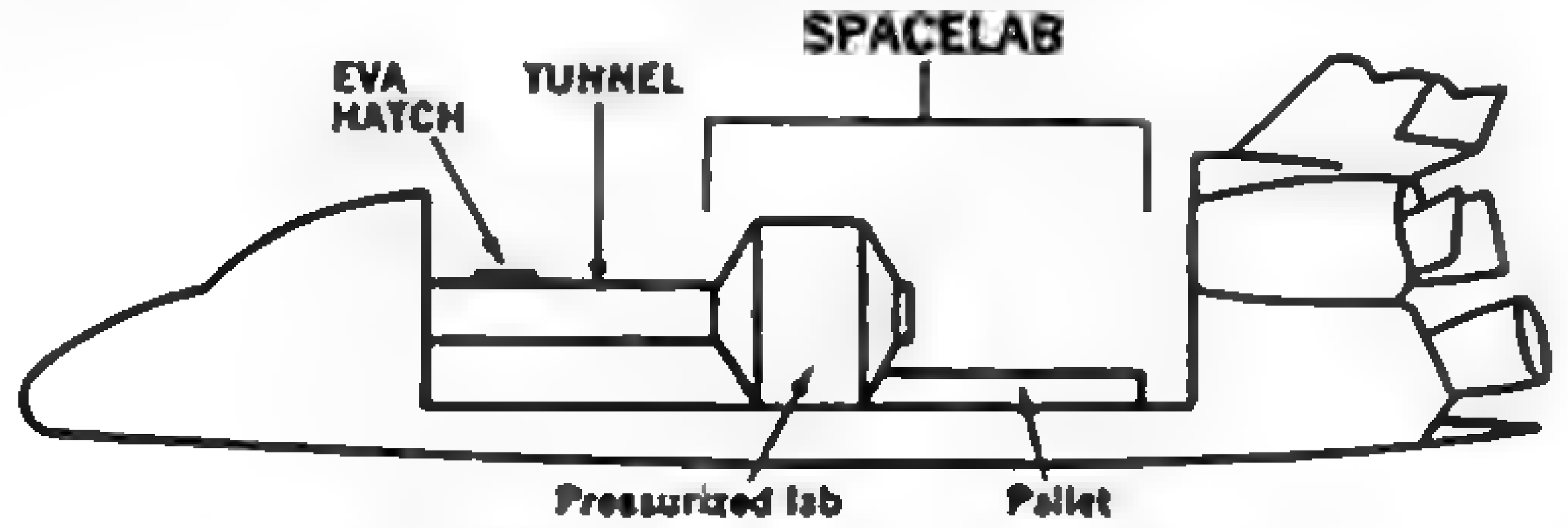


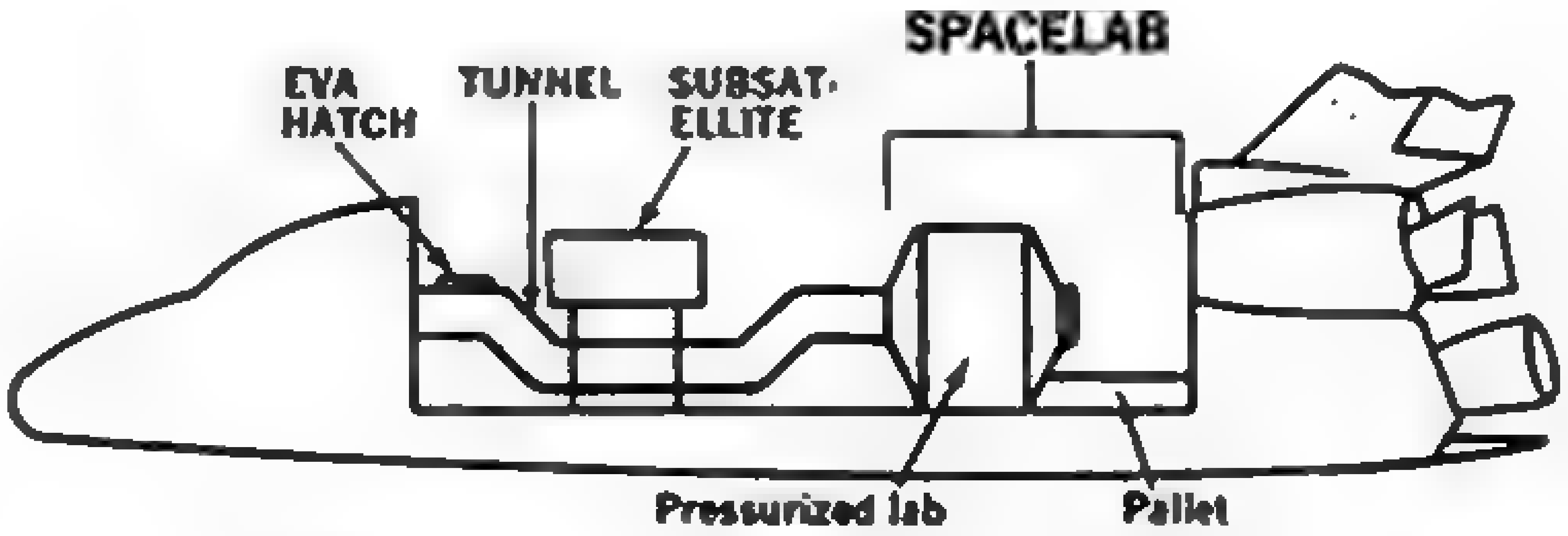
In zero gravity, Spacelab crew will float with greatest of ease through tunnel from Shuttle to their pressurized workshop—and back, for eating and sleeping. Weightlessness permits variety of positions for reaching anything from windows at top to gear below lab's floor level (inset from ERNO).

Center of gravity governs placing of modules

Examples show how Spacelab modules, and anything else sharing Shuttle cargo bay, will be arranged to place center of gravity so Shuttle will fly right. Payload may also include a subsatellite to be launched in orbit; extra fuel tanks to reach higher orbit; and a docking module for other spacecraft. Shuttle-Spacelab tunnel will vary in length up to about 13 feet, and may sometimes have an EVA hatch.







[Continued from page 73]

der the ground rules of most European multinational projects, the prime contractor would be a West German firm. After a spirited competition, the winning candidate was chosen in June 1974: the VFW-Fokker/ERNO group in Bremen. Other participating companies work as subcontractors, regardless of nationality.

Countries taking part in the venture include Belgium, Denmark, France, Germany, Italy, the Netherlands, Spain, Switzerland, and the United Kingdom. Engins Matra of France is responsible for data acquisition, distribution and processing systems, and equipment such as telephones and closed-circuit television. Aeritalia of Italy is in charge of the module structure and thermal control. Hawker Siddeley Dynamics of England builds the pallet structures, while Kampsax of Denmark prepares computer software.

ESA, the European Space Agency that succeeded ESRO last May, is the present contracting agency. Its European Space Research and Technology Center is in Noordwijk, Holland. Because of the complex interconnections between the Spacelab and our Shuttle, ESA is in continuous contact with NASA, for which the Marshall Space Flight Center at Huntsville, Ala., carries the ball.

How it's coming along

The right-on-schedule progress to date shows the success of the ESRO-ESA plan of Spacelab-program management. As early as last June, the full-scale Spacelab mockup (a "soft" one) pictured on this article's opening page was on view to ESA and NASA experts in a Bremen hangar. It was based on half a million printed pages of data and specifications produced in the first year of work. The working model including subsystems, to be ready this year, will be a "hard" mockup. Spacelab's development phase will be completed in 1978 with delivery of the first "engineering model" of Spacelab.

The standardized ready-for-flight Spacelabs will follow by 1979, in ample time to ride Space Shuttles in 1980. NASA is expected to order a substantial number of them from the West German maker.

Thus, a subsequent mission will not need to be held up until a Spacelab returning to earth is refitted with science gear for an entirely different purpose. A spare Spacelab can have been suitably equipped and ready to install at once in place of the returning one. In turn, that one can be refitted as the next Spacelab is in orbit.

Each Spacelab can carry up to nine tons of scientific equipment; will have a life of about 10 years; and will serve for some 50 week-long missions. They will open a new era of space studies by leading scientists and technologists "on location."

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National Space Institute

you can join

Dr. Wernher von Braun, president of NSI, announces its birth to the press.

A new organization of amateurs and experts, paying modest dues, can help to shape ventures beyond the earth

By **WERNHER von BRAUN**
PS Consulting Editor, Space

A space group newly founded within the past year, open to amateur space buffs and technical experts alike, will give the public a greater voice in supporting and shaping our future space program. Called the National Space Institute (NSI) and made up of members in all walks of life, it will be a nonprofit, self-supporting forum of public opinion expected to influence both NASA, and Congress, which allocates NASA funds.

Individual NSI members will pay annual dues ranging from only $9 (if 18 or younger) to $15 (if older). A life membership will be $100. There is a $1000 fee for corporate membership, since a company can anticipate substantial returns from space-derived technology to which it will have access.

Congress hails NSI

NSI has been warmly endorsed in Congress, where Sen. Wendell H. Ford says, "It is one of the finest things I have seen come down the pike in a long time."

As for NASA, it has long recognized that its excellent staff has no monopoly of good ideas. Examples have shown it stands ready to adopt projects and experiments proposed by outsiders.

Its synchronous satellites, hang-

ing stationary above a fixed point on Earth, were originally the suggestion of a talented science-fiction writer, Arthur C. Clarke.

And, never underestimating the merit of youthful imagination, NASA invited school kids to contribute suggestions for some of the experiments carried aboard Skylab. One of the best was to see whether spiders could spin webs in zero gravity. (Surprisingly, they could.) A schoolgirl, Judith S. Miles of Lexington, Mass., proposed the trial.

What NSI members get

Members of NSI will receive a monthly newsletter of activities; NSI has hopes of publishing a space magazine, too. Members will also get educational material as available. They will be entitled to ask far-out questions about space technology and get authoritative answers.

A sample was the query from 15-year-old Paul Domine of Waukesha, Wis.: "Could antimatter be used for fuel aboard space vehicles?" "Yes," replied a leading scientist. "Never done, but conceptually it can be done. Although antimatter and ordinary matter are annihilated upon contact, we can manipulate antimatter without touching it, by using electric, magnetic, or other fields. A small amount [which can be made in large atom smashers] could heat a much larger amount of regular matter and provide thrust energy. It would be difficult and expensive and there may be better fuels . . ."

To champion U.S. strength in space, willing members can become NSI's spokesmen and carry its message to friends, associates, and others. The Institute provides fact sheets for public speakers, and literature to distribute to campaign for recruits—who now have an organization to back their views. A speakers' bureau is being formed, and NSI will recommend individuals to appear on programs in their parts of the country.

NSI is designing a "space-product seal" that approved makers could apply to popular commercial articles based on space technology. The public, we think, will be quite surprised to find so many products of research originally done for the space program. Anything that has been miniaturized—hand-size calculators, digital wrist watches—would not be on the market but for the incessant drive to make spacecraft smaller, lighter, and more intelligent.

Von Braun, NSI's head, aims to boost space program

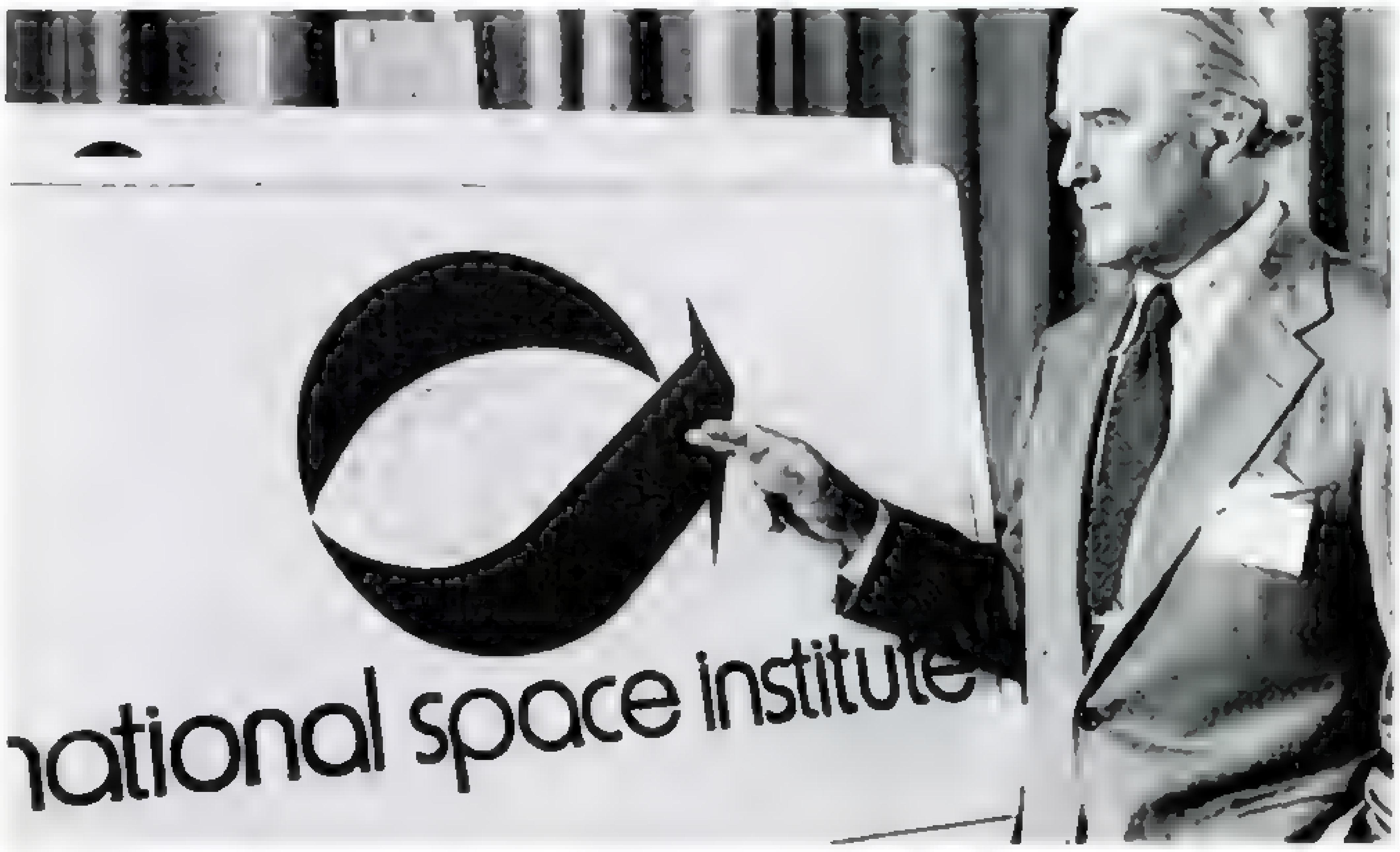
At 63, as president of the new National Space Institute, PS's distinguished Consulting Editor for Space leads a campaign to rally lagging public support behind the nation's space program. His brilliant achievements well fit him for the task:

When Russia's Sputnik beat our much-touted but ill-starred Vanguard satellite into orbit, President Eisenhower turned to von Braun to launch our first successful satellite, Explorer 1.

When President Kennedy called for landing an American on the moon before 1970, von Braun made good with his fantastic Saturn V moon rocket.

Now the National Space Institute, headed by von Braun (photo), gives promise of setting the course for even greater space adventures of the future. Here is its story, told by himself.

A German-born American, von Braun has successively served America in the Army Ballistic Missile Agency and then in NASA, where he directed the Marshall Space Flight Center at Huntsville, Ala., and later became Associate Administrator in charge of planning at NASA's Washington headquarters. Since leaving the government post he entered aerospace industry, becoming Fairchild's vice-president for engineering and development. His new NSI role opens a way to advance the space interests of all the people, in liaison with NASA, Congress, industry, and everyone else.—*The Editors*



Remarkable estimates of what space technology is worth to nonspace users came from a recent study for NASA by a research group called Mathematica, Inc. It chose just four fields for analysis: cryogenic multilayer insulation, for tanks of ultracold liquefied gases; gas turbines; integrated circuits, for microminiature electronic gear; and NASTRAN (NASA structural analysis), a far-advanced computerized way to design spacecraft, but applicable as well to entirely different things such as airplanes, automobiles, or trucks. To the investigators' own amazement, the value of "spinoff" to U.S. industry for just these four items, by conservative estimate, totaled $7 billion. This is twice the amount earmarked for expenditure by NASA in its annual budget.

While NASA has done its best to encourage such down-to-earth uses of space technology, many manufacturers still have never heard of them. NSI plans to help spread the good tidings.

Space is "endless frontier"

I see space as the endless frontier that can catch people up in an enterprise more exciting than the discovery of the New World, or the conquest of the American west.

The effort of several hundred thousand devoted Americans to put men on the moon was history's most concentrated and massive endeavor in time of peace. But history will look back on our space achievements to date, I think, as just a pioneering beginning.

At a two-day NSI symposium in Washington, D.C., early this year, 15 speakers looked at the future of space. Minerals can be mined on the moon, in the asteroid belt, and on nearby planets in the next century. Satellite power plants can banish concern over limits of energy on Earth, and run factories in orbit. Permanent inhabited bases on the moon or Mars, and orbiting colonies of hundreds of thousands of people, built with material from the moon, will offer new places to live—a chance to organize a new interplanetary society, and make fresh beginnings.

For further information write to National Space Institute, Suite 408, 1911 N. Fort Myer Drive, Arlington, Va. 22209.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The search begins for

Life on Mars

Twin landing craft of Viking 1 and 2 lead a $2-billion expedition to the mysterious surface of the Red Planet

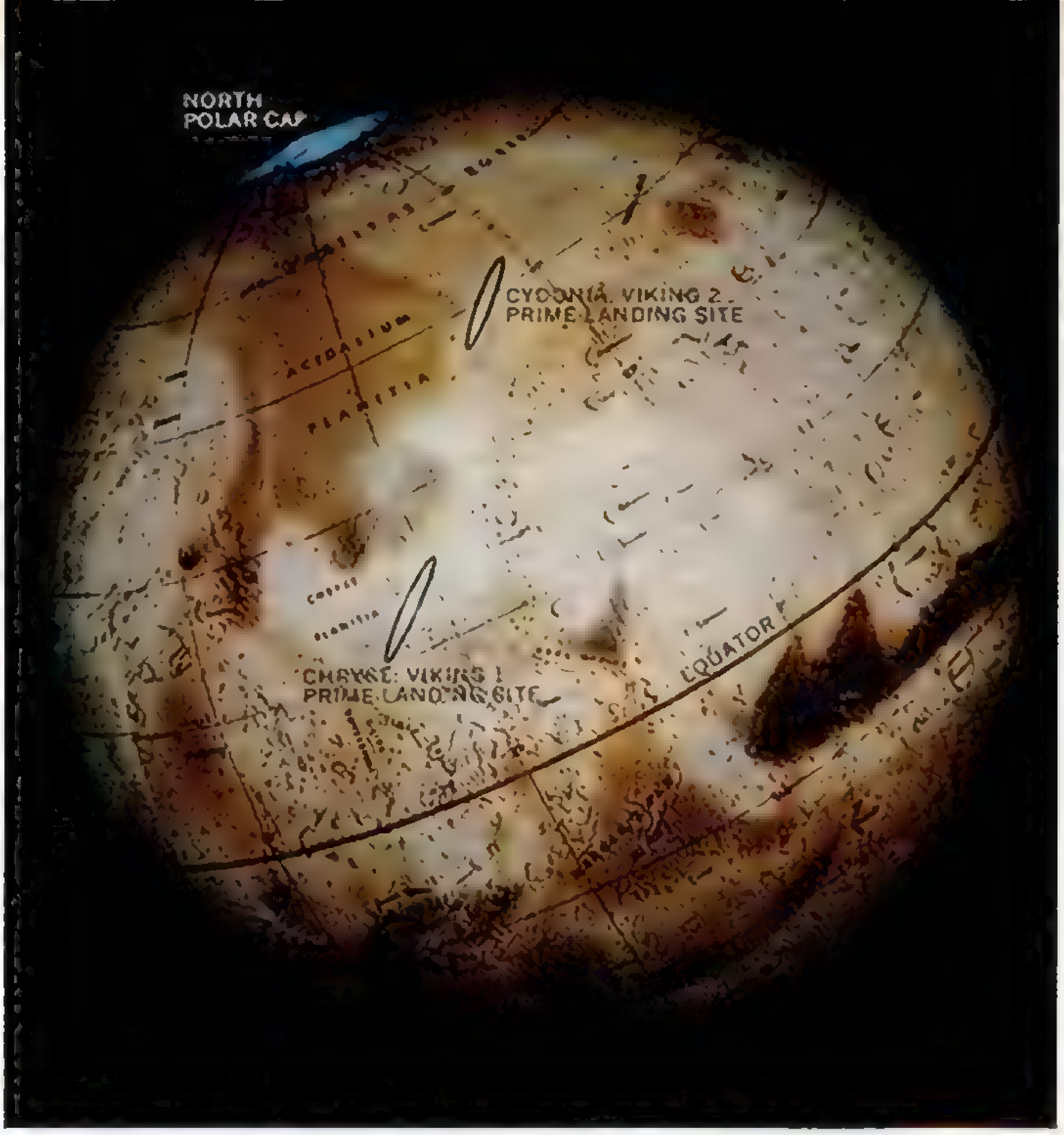
By WERNHER von BRAUN
PS Consulting Editor, Space

Within the next few weeks, it's possible that an electrifying radio report from 200-million miles away will tell the world that there's life on the planet Mars, a discovery that would surely rank among the most important ever made by man.

The word could come a few weeks after Viking 1 touches down on the Red Planet about July 4, a fitting way indeed to demonstrate the incredible scientific progress made during the 200 years since the birth of our Republic. Or, it could come after the descent of the Viking 2 lander about Sept. 9. Each craft will send a report after biological tests that will begin about

Marsbound, Viking 1 rides in nose of our biggest interplanetary rocket, four-stage Titan 3E, at successful launch last year. Viking 2 followed shortly. Curving trajectory is taking them on 505-million-mile journey to Mars, 200-million miles distant from Earth. Then, each Viking orbiter-and-lander will release the landing craft to descend on Mars' surface in search for life there. Powerful TV cameras on orbiters will first check out tentative landing sites. If unfavorable, they are subject to change in favor of better ones up to the last minute.

Blazing rocket jets check fall of a Viking lander from height of 4000 feet, after parachute drop, as it approaches soft landing. Sensors on footpads cut off three landing engines just before. Their nozzles tilt outward so exhaust gases won't contaminate soil samples. Cameras in twin turrets film Martian landscapes, making color and stereoscopic views.



Where landers come down is marked by ellipses on map of Mars. Tentative site for Viking 1's landing is called Chryse ("land of gold") at mouth of valley, which dwarfs our Grand Canyon. For Viking 2 it is Cydonia, near rim of north polar cap. Possible traces of water at either site would favor finding life.

eight days after touchdown and will take some 12 days to complete. These tests are designed to reveal the presence of microorganisms—the most likely form of life on Mars, if there is any at all.

While it is even more unlikely that there are higher animals, a Viking lander's two TV cameras could detect them.

Biology experiments

Three principal life-detecting devices are aboard each Viking lander. This "biology experiment," housed in an unpretentious box the size of a large suitcase, is undoubtedly one of the most sophisticated pieces of scientific equipment ever built by man. It contains three automatic labs, a computer, tiny ovens, counters for radioactive trac-

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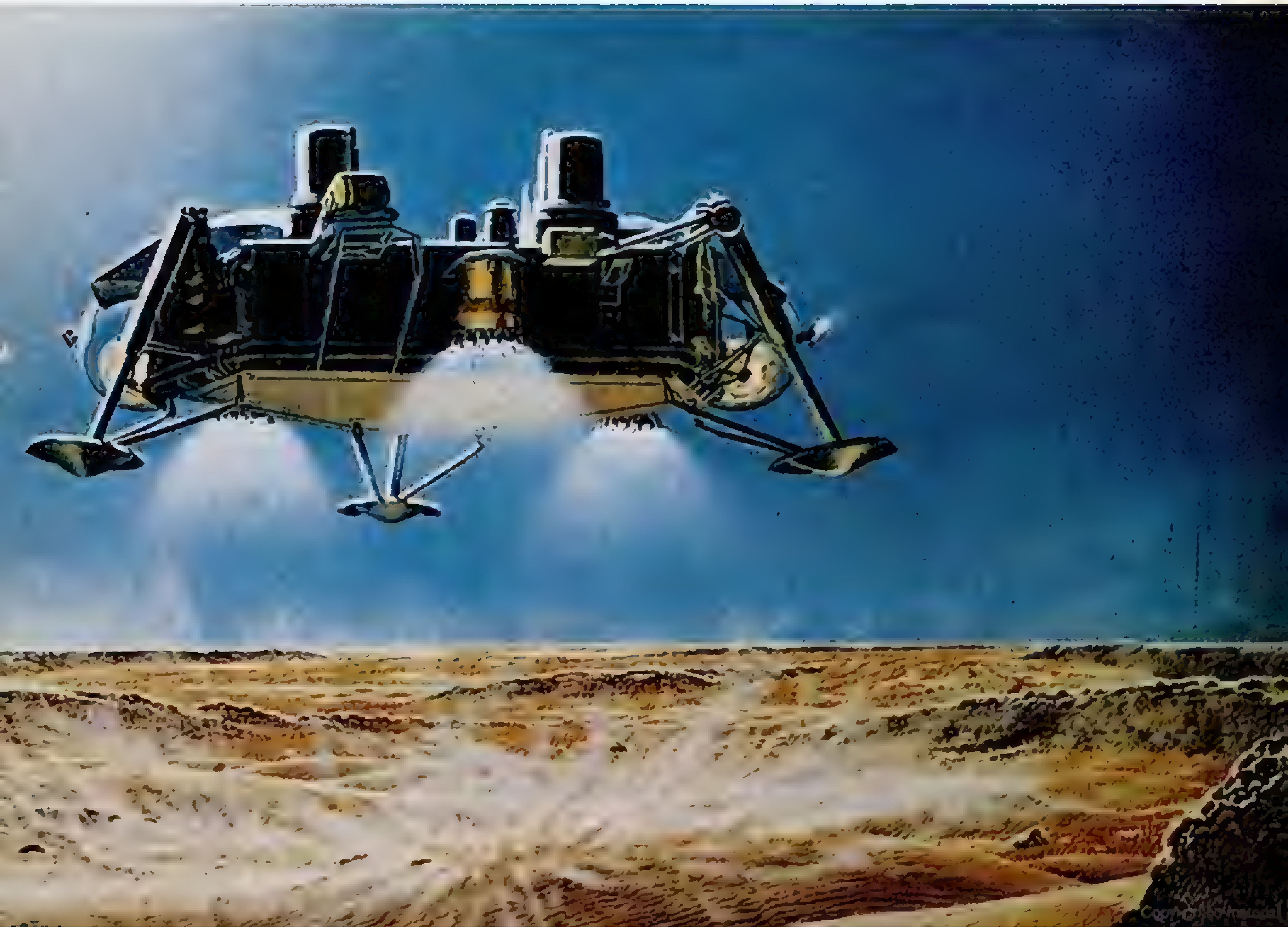
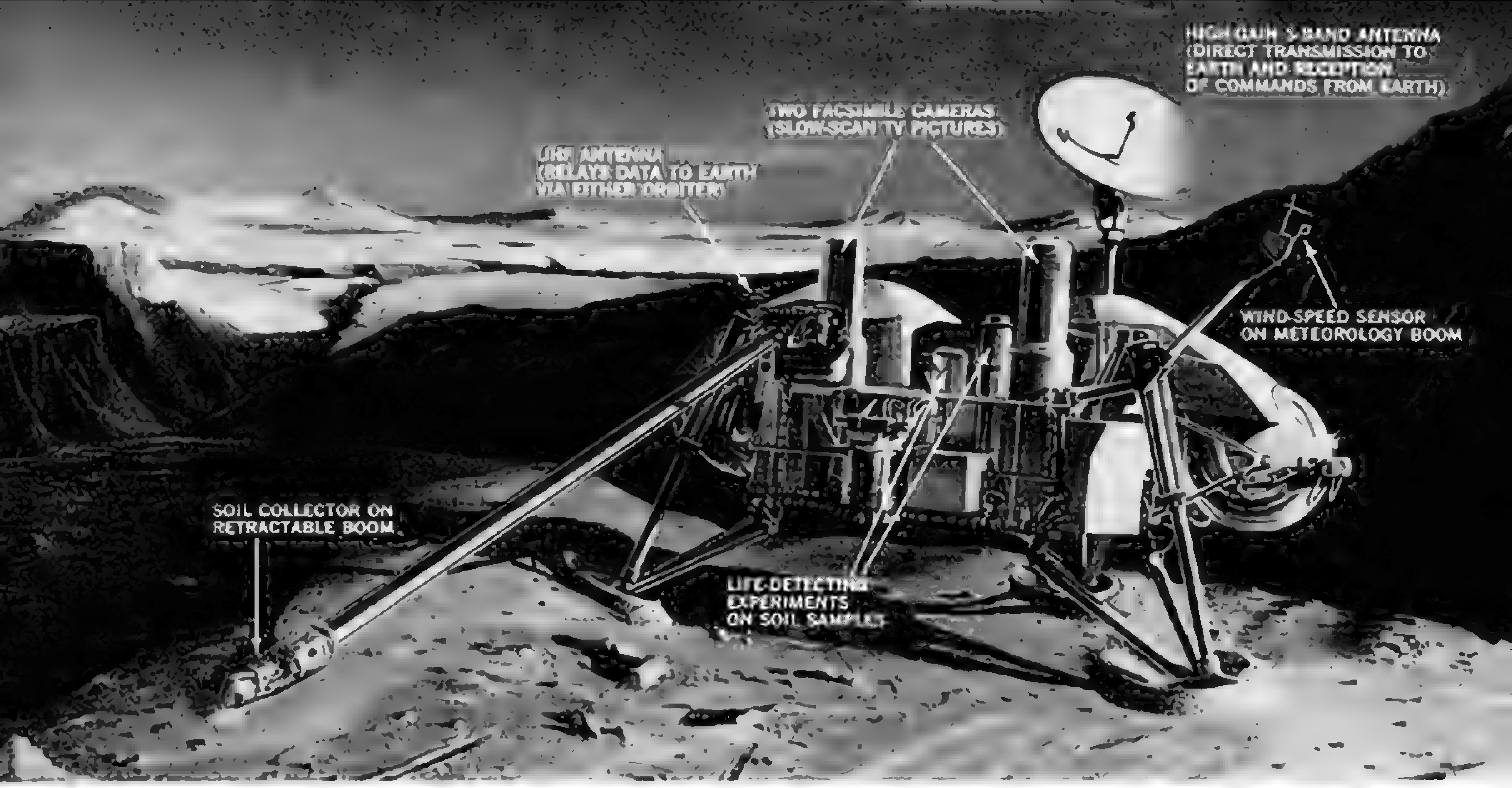




Perched on Mars, Viking lander goes into action to take first picture. Full scene takes 20 minutes to scan. Then search for life, in samples scooped up by retractable boom at far left, begins. Findings go to Earth directly, via big dish antenna atop lander, or to orbiter for relay to Earth from another antenna. Lander's "smart" computer can operate it automatically for 22 days, but program can be updated by command from Earth if needed, after lander sends its reports.

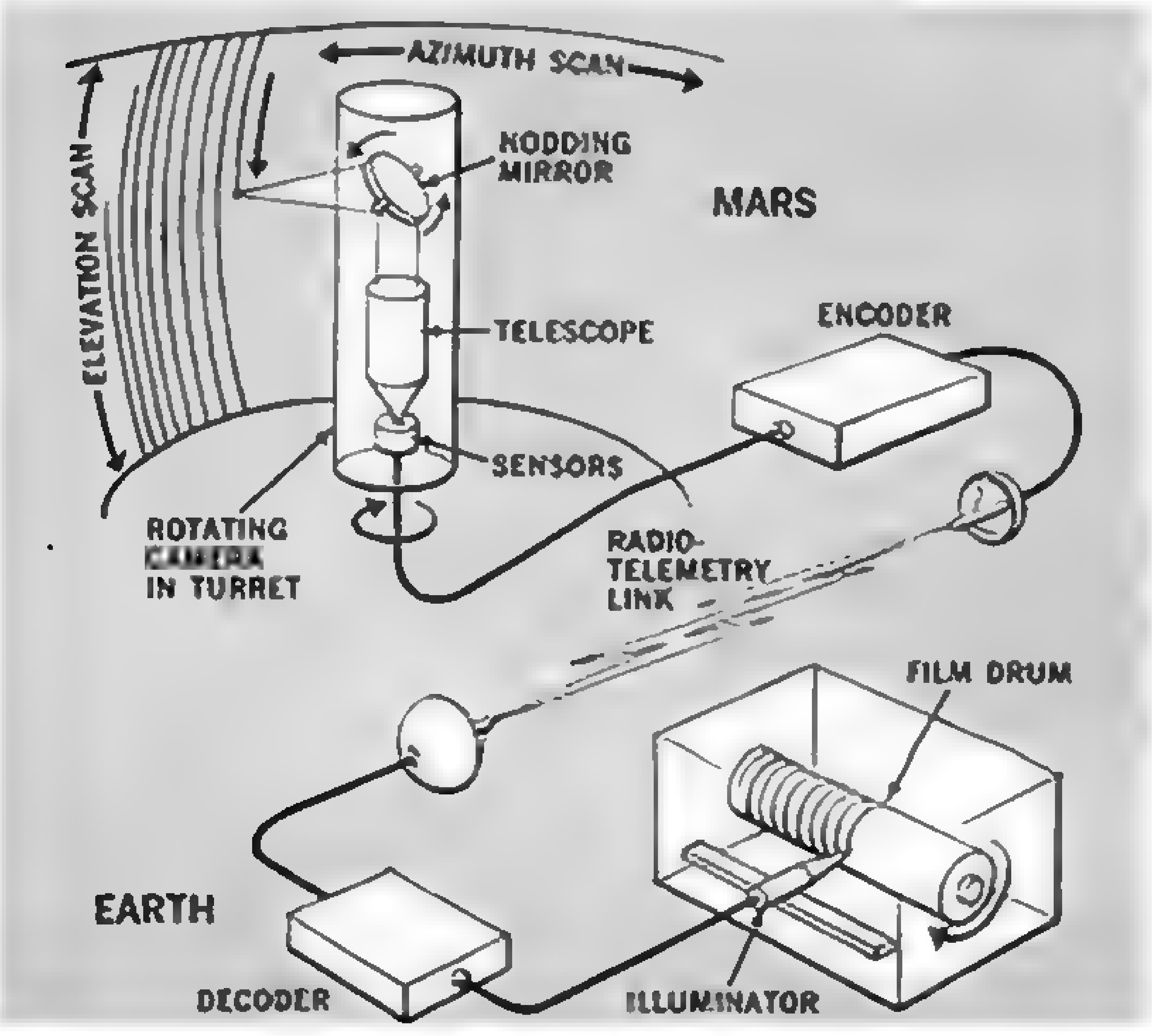
ers, filters, a sun lamp, a gas chromatograph to identify chemicals, 40 thermostats, 22,000 transistors, 18,000 other electronic parts, and 43 miniature valves. The biology instrument will make these chemical tests for living things in soil samples the lander scoops up:

- A *pyrolytic-release experiment* will measure photosynthesis of carbon dioxide and carbon monoxide in Mars' atmosphere. Some of Mars' potential fauna could announce themselves in this way.
- A *labeled-release experiment* will test Martian creatures' ability to break down water solutions of simple organic compounds to carbon dioxide—another sign of life. The compounds' carbon will be labeled with radioactive C-14 to trace its progress.
- A *gas-exchange experiment* will reveal assimilation of CO_2, nitrogen, methane, hydrogen, and oxygen by soil organisms—if they are there—in moist nutrients.

Although no single test will positively confirm life by itself, a team of scientists should reach a pretty certain conclusion if all three point to living microorganisms.

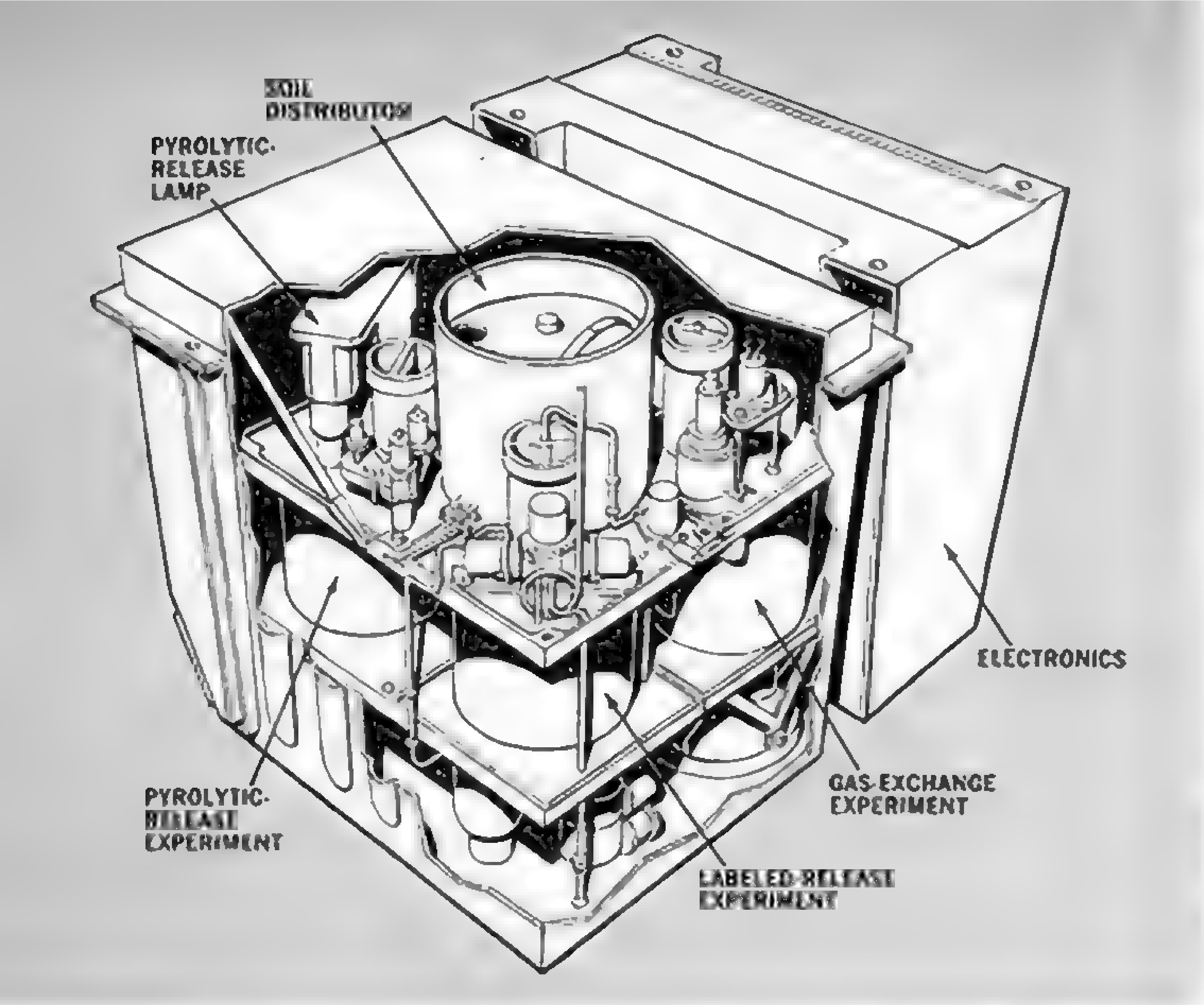
Landers' cameras

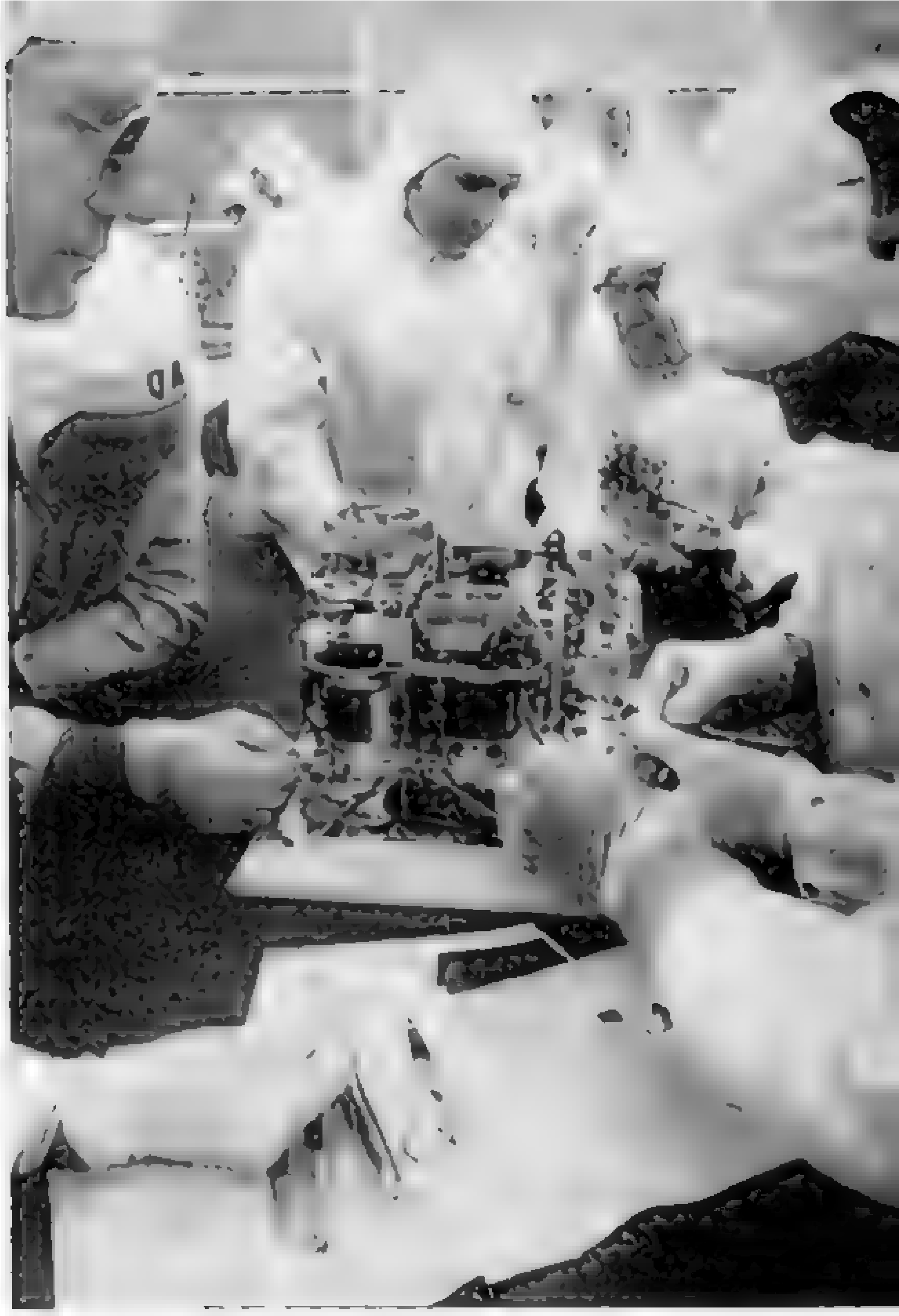
Whether larger forms of life exist on Mars will be for a Viking lander's cameras to tell, something orbiting cameras couldn't do. Mariner 9's photos of the Red Planet's surface [PS, Feb. '71], magnificent as they were, couldn't have revealed a herd of 10-million elephants crossing the scene. It will be another story for the lander cameras. Each lander is equipped with two cameras, spaced 39 inches apart, and capable of taking a panoramic view of the landing site. They will be actuated within about 10 minutes of touchdown. As it takes the slowly rotating cameras and their nodding mirrors about 20 minutes to complete one 360° scan, and the radio signals another 20 minutes to cross



Lander cameras use mechanical scanning. Nodding mirror and rotating turret do it (left). Some periods of rescanning same vertical line will detect passage of a moving object—a possible hint of "big game."

Actual camera, built by Itek Corp., shows heart of the instrument pictured in diagram at left. Radiophoto method recreates its still-life views on film 200-million miles away on Earth (bottom of diagram).





Biology instrument contains three principal life-detecting devices, soil-sample dispenser, and electronic gear. Main tests, called pyrolytic-release, labeled-release, and gas-exchange experiments, detect chemical processes pointing to existence of life. Panel of experts will decide whether they settle question.

Amazingly compact size of biology instrument built by TRW Systems Group is shown in photo above. This is no model of it, but the real thing.

the 200-million-mile distance from Mars to Earth, we can expect the first surface photos from Viking 1 and 2 to arrive on Earth about one hour after touchdown. The twin cameras can also provide stereo and color pictures. Their slow mechanical scanning will restrict them to "still-life" photos, but they will be able at close range to view objects as small as an aspirin tablet.

They wouldn't be able to sharply picture a moving animal—as unlikely as that presence would be, in the opinion of most scientists—but could indirectly record its passage across the field of view. At certain times their rotating motion to build up a panoramic scene will be stopped. Then their nodding motion will repeatedly trace a single vertical line. If nothing moved, each line should be identical. But if one or two successive lines display a dark or light spot unseen before, the "single-line scanning" method will have revealed an Unidentified Moving Object, possibly alive.

A fruitful hoax

In a preflight test of the Viking cameras, scientists viewed a simulated Mars landscape. Viking control got an unscheduled surprise when the first picture revealed marine fossils that team members had surreptitiously strewn on the sand. It was a worthwhile prank, since the picture proved sharp enough for a scientist to identify them at once as Earthly trilobites.

The two Viking landers and their pair of orbiters will be busy craft indeed, for other purposes than detecting life on Mars. The three main biological experiments are covered in only about six pages of a 120-page NASA press kit detailing the Vikings' program and equipment. As this would suggest, the twin missions' total $2-billion cost will by no means have gone down the drain even if, as some scientists foresee, no life of any kind is detected.

Prize trophies will be the lander cameras' eye-level view of Martian surface features—seen previously from no nearer than the remote viewpoint of Mariner 9's orbit. (When Russia attempted it with the jinxed Mars 3 soft lander, its transmitter went dead in only 20 seconds, not enough to complete a single frame or show anything recognizable. Some speculated the craft had been toppled by a sandstorm in which it landed.)

A typical daily picture budget for one lander might be one picture transmitted to Earth directly from the lander, two pictures transmitted at higher rate via the orbiter, and three more views spread on tape for relay later. Also, at times, the single-line motion-detecting technique referred to earlier will be used.

Where to land a Viking

Judging by standards on Earth, the most favorable sites for life will be spots where Mars' scanty water occurs, or once flowed. Viking 1's primary site will be a region called Chryse ("land of gold") at the mouth of a huge former watercourse called Valles Marineris (valleys of Mariner), dwarfing our Grand Canyon. Coprates, once thought to be one of the Martian "canals," forms a part of them. Viking 2's target, called Cydonia, lies not far from Mars' north polar cap, at least partly a thin sheet of frozen water that melts and recedes in the Martian summertime.

These sites will be reexamined by Viking's orbital cameras, surpassing Mariner 9's, before the final choice is confirmed and the landers swoop down. (Viking 1 goes into Mars orbit June 19.) One reason for being fussy about the sites is to avoid the embarrassment of landing on bare rock, where a Viking would be unable to scoop up loose soil to test.

Before the combined Viking orbiter-and-lander detaches its surface craft, it will weigh about 7500 pounds overall. The lander itself weighs 2375 pounds. Its orbit-to-surface trip will take some three to five hours, including the 10-minute passage through Mars' thin atmosphere.

After the lander has been slowed by aerodynamic braking from its initial reentry speed of about 10,000 mph to about 900 mph, it will unfurl a parachute—at 21,000 feet

[*Continued on page 121*]

[Continued from page 81]

—to slow it down further. Then, at an altitude of less than one mile, it will fire its three terminal-descent engines to make a soft landing. Each is a cluster of 18 small nozzles, tilted outward so as not to contaminate the soil samples to be taken with their exhaust gases. Sensors on the lander's footpads cut off the engines for touchdown.

Computer and power systems

A Viking-lander report to Earth and an Earth command in response would take about 40 minutes (20 minutes each way). Since this would be prohibitively long for such purposes as guiding the scooping up of samples, a Viking lander is equipped to operate as long as 22 days automatically without contact with Earth.

It does so with a unique computer "brain" called the Guidance Control and Sequencing Computer (GCSC), an electronic wonder designed especially for the lander. This is possibly the most sophisticated single piece of equipment on the lander. Power for instruments and heating comes from radioactive thermoelectric generators. They are superior to a solar-powered system because sunlight is only half as strong on Mars as on the Earth in daylight, and is nonexistent during the frigid Martian night, when the temperature may drop to −184° F.

Much additional valuable data about Mars will come from other experiments aboard the landers: Chemical analyses of Martian soil samples should confirm or refute, for example, current opinion of what gives Mars its ruddy hue. Rust-like compounds of iron could do it, in the latest view.

The lander will have an automatic weather station, including a wind indicator capable of recording Mars' fierce gales, whose wind speeds are estimated at 125 to 185 miles an hour.

Also aboard the lander will be a seismometer to detect and record "Marsquakes." The most spectacular signs of present or past volcanic activity on Mars are its huge volcanoes, rising up to 15 miles high. The largest one, Olympus Mons, has no counterpart on Earth in size.

Finding life on Mars would, of course, be the jackpot. But even if we don't, that doesn't prove there isn't any. We might have picked the wrong places to try. Or our experiments might not have asked the right questions, for Mars' inhabitants may prove more exotic than we dreamed.

Vikings of the future will give us another try. They may land roving vehicles to seek more promising sites, and even robot craft to bring samples back to Earth, according to concepts already on the drawing boards.

And should, against all expectations, an intelligent Martian confront a Viking lander and analyze it in detail, he may well conclude that he is dealing with a pretty intelligent visitor from space.

For further reading

The Viking Mission to Mars, NASA publication SP-334, 1974.

Viking '76: The Search for Life on Mars, TRW Systems Group publication, 1976.

"Ninety Days on Mars," *Spaceflight*, July 76.

"Viking to Mars: The Mission Strategy," *Sky & Telescope*, July '76.

Popular Science

The What's New magazine

Coming: Aircraft that use half as much fuel! By Wernher von Braun

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Close-ups at the new models from Ford and Chrysler

Nutcracker VTOL
folds in flight

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- Dry-mix cement know-how
- Shaker utility room

Fuel-saving aircraft

New technology promises more passenger miles per gallon

Many-faceted NASA program to boost airliner efficiency includes such innovations as winglets, flexible skins, and laminar flow control

By WERNHER von BRAUN
PS Consulting Editor, Space

During the 1990's, a sleek new generation of wide-body airliners that use half the fuel guzzled by today's jumbo jets should go into service. As you walk aboard these new aircraft, you'll see some of the innovations responsible for this remarkable fuel saving.

The wings, for example, will be strikingly long and narrow to supply extra lift. A flat-topped supercritical wing planned for NASA's Mach-1 airliner [PS, April '72] makes this glider-like design feasible. Each wing will be tipped with small airfoils called winglets. These short, slanted surfaces, similar to the wing tips on buzzards and other soaring birds, will provide extra thrust.

Look closely at the wings and you may notice a porous or slotted surface instead of the mirror smoothness on today's aircraft. Turbulent air just above wing surfaces will be sucked in through these holes. Part of the aircraft body may even have a *flexible* surface —a compliant fuselage surface that might help future airliners knife through the air much as a porpoise's flexible skin enables it to speed through water.

Lightweight, super-tough composites—fibers of graphite or boron embedded in epoxy resin [PS, April '75]—will eliminate many metal aircraft parts, shaving off fuel-wasting weight. Advanced engines, operating at fuel-efficient higher temperatures, will power your plane. Sensors that detect turbulence will smooth your ride and save fuel by feeding signals to computers that in turn will activate aircraft-control surfaces.

Slowing down

Until recently, the time-honored formula for changes in airliner design has been simple: Any airliner had to be faster and more comfortable than its predecessor. But the blockage of commercial overland supersonic flights, an Arab oil embargo, and a tripling of overseas jet fuel prices have clearly signaled that fuel efficiency, not speed, is the name of the game.

The appearance of future aircraft should reflect this change of attitude. The new breed of fuel-efficient airliners will probably look much like today's planes, and most of them are likely to be flying along at kerosene-saving speeds of Mach 0.8 (about 600 mph). The needle-nose supersonic designs have proven to be wasteful of fuel.

Last year, nudged by aviation-minded senators Frank Moss and Barry Goldwater, NASA consulted 200 industry and government experts to prepare a technology-development program for new fuel-saving aircraft. The NASA task force has reported that moderate gains in fuel economy are possible within a few years. Some fuel-saving improvements could even be retrofitted on existing airliners. But other fuel-saving gains, for use 10 to 15 years from now, will require new materials and technology, plus extensive studies in wind tunnels. Here's a rundown of the more important changes you can expect.

Laminar flow control

One of these more advanced proposals, laminar flow control (LFC), promises dramatic fuel savings. By smoothing airflow over the plane's skin, LFC could eliminate roughly half the air drag on a subsonic airliner. Normally, the so-called boundary layer just above an aircraft's skin is filled with turbulent eddies of air. These eddies create air friction, making the engines work harder.

Ten years ago, an experimental USAF X-21A demonstrated that by sucking air into its wings through numerous small slots, airflow in the boundary layer became eddy-free or "laminar." The laminar-flow-control project did not proceed beyond the demonstration stage, in part because of unsuitable air-pumping equipment. Another problem was the partial blockage of suction slots by insects. LFC experience under conditions of icing and severe rain is still limited, but these may cause problems, too.

Aviation engineers expect to solve these problems: Jet-engine compressors have a tremendous suction capability and are an obvious pumping source to achieve laminar surfaces; lightweight panels of porous composite materials may be used for these surfaces, and might alleviate the problems caused by adverse weather.

NASA estimates that a whopping 20- to 40-percent fuel saving is possible on LFC-equipped airliners,

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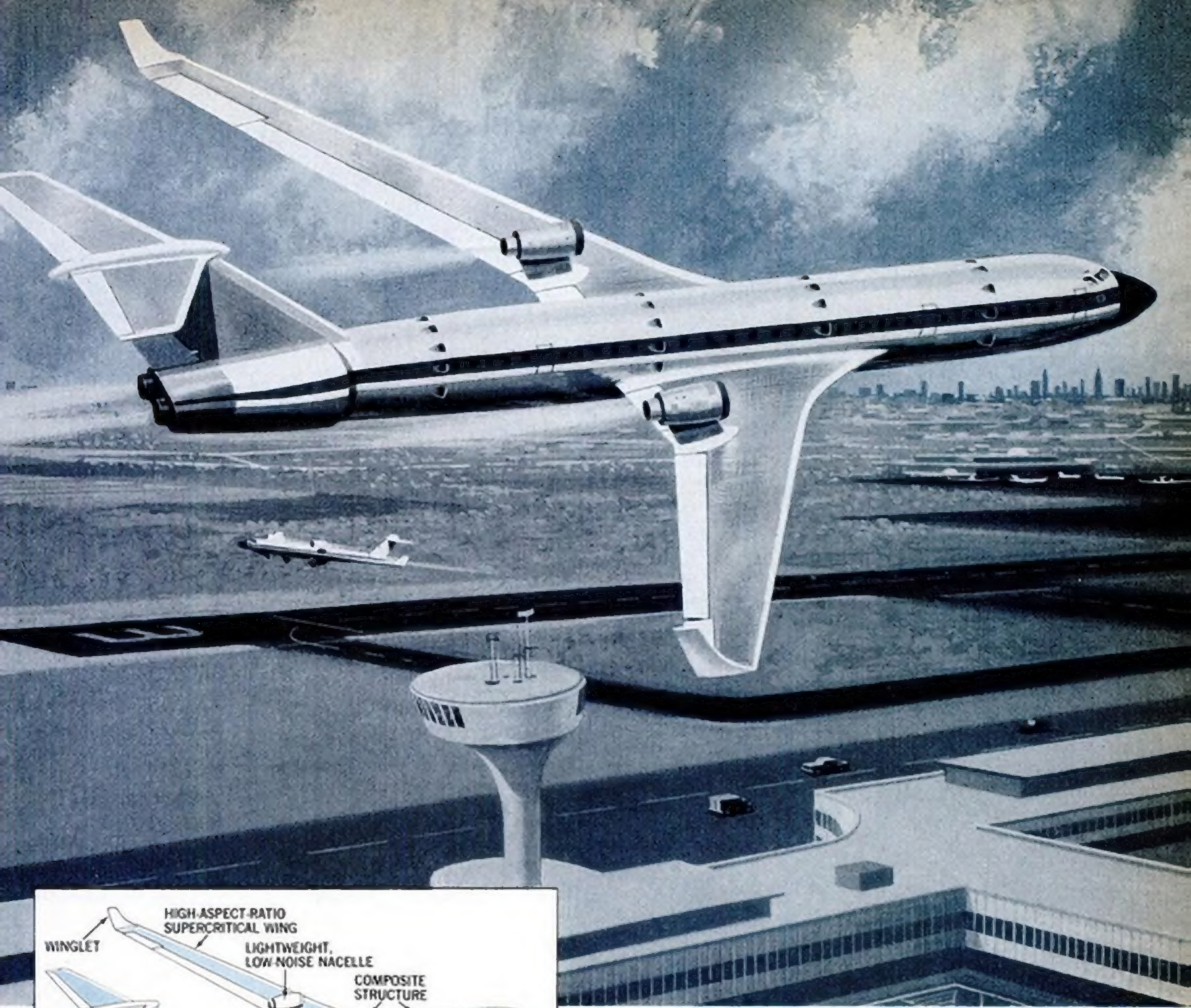
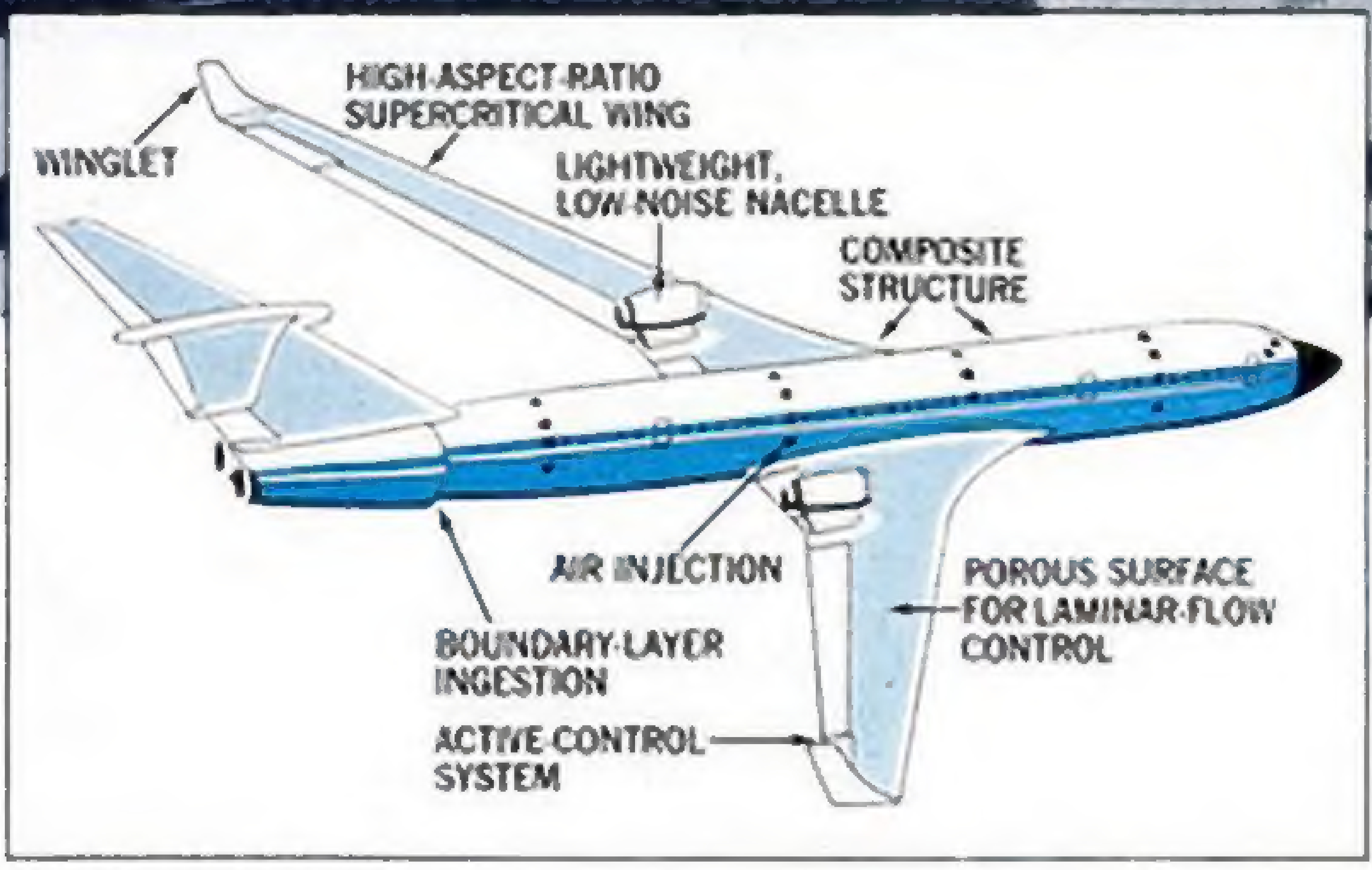
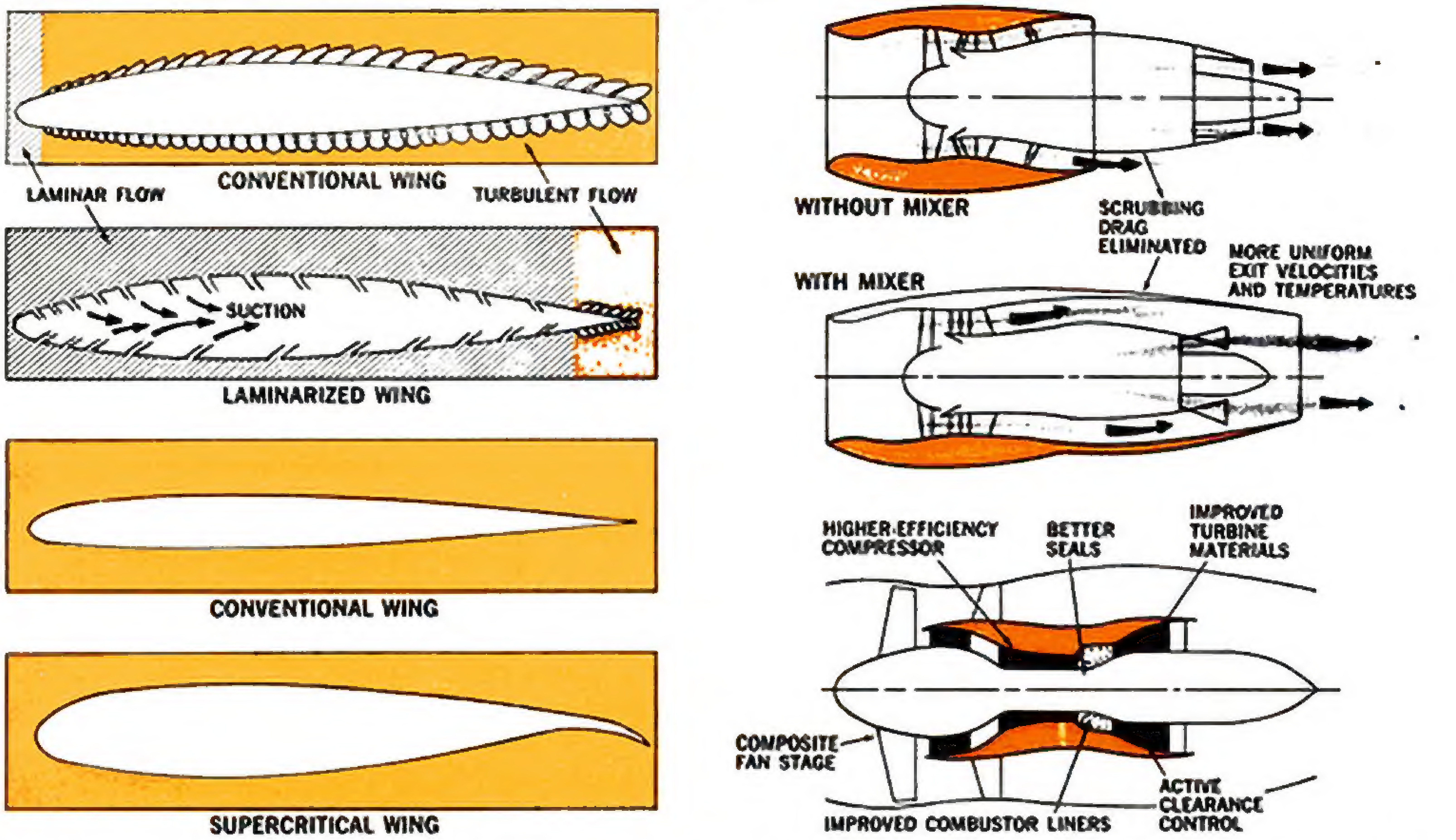




Glider-like wings will give fuel-saving extra lift to this 1990's jet, based on a NASA model. Other fuel-efficiency boosters: laminar-flow-control systems that suck in turbulent air on wings and tail, or blast it away from fuselage; light, stronger-than-steel composite materials that reduce aircraft weight.

Turboprop passenger transports (in model form below), may reappear in fuel-efficient designs like this. A recent Lockheed study found that such prop-fan planes would use 18 percent less fuel than turbofan aircraft at the same cruising speed.

Aerodynamic and engine technology for fuel efficiency



Drag reduction with laminar flow control (LFC) on wings and other surfaces (upper left) could achieve 20- to 40-percent fuel savings. Suction in wing minimizes turbulent air near surfaces. Flat-topped supercritical wing (above, left) can be built thicker than conventional wing—without increasing drag. Thicker wings permit longer spans that improve aerodynamic efficiency. Mixer technology for jet engines (upper right), tested in models, indicates that blending core and duct streams can boost propulsive efficiency and save fuel. A variety of improvements will go into advanced turbofan engines (above, right). The goal is to increase engine temperatures and pressures for improved thermodynamic efficiency. The new fan-jet design might cut fuel consumption by 10 to 15 percent.

depending on how much of the craft's surface is laminar-controlled. Some drag reduction might also be achieved by injecting air into the fuselage's boundary layer through numerous larger slots facing aft. However, even with a $100 million NASA investment during the next decade, don't expect LFC airliners before the 1990's.

Several other projects are underway to reduce aerodynamic drag and improve lift. At NASA's Langley Research Center, wind-tunnel tests have shown that slightly flexible surfaces (sheets of Mylar-coated compressed foam) can reduce air-friction drag by 20 percent. Such compliant surfaces yield to rapid pressure changes within the boundary layer.

Curiously, an aquatic mammal, the porpoise, may be the inspiration for some future aerodynamic designs. Porpoises have a flexible, duct-filled skin that enables them to race at high speeds through the water. Aircraft designers, familiar with this principle, may one day pattern fuselage surfaces after the porpoise's resilient skin. However, a tough, durable material for aircraft must be developed first.

Another aerodynamical improvement called winglets might be added to some existing aircraft. Winglets are short vertical surfaces mounted on wing tips and slanted slightly outward. The vertical surfaces interact with air flow from the wings, producing a net forward thrust. NASA estimates winglets might provide a five-percent fuel saving.

Fuel-saving wings

The supercritical wing, a radical innovation developed by Dr. Richard Whitcomb of NASA, has been used largely for military and experimental aircraft, although modifications of the original design have been adapted for limited commercial use [PS, April '75]. The wing's flattened top reduces the drag produced by the shock waves that develop as a plane approaches supersonic speeds, and enables the plane to go faster without sharply increased drag.

The supercritical wing could conserve fuel, too. The novel wing can be made up to 50 percent thicker than conventional wings without a loss of efficiency. Thicker wings permit the wing span to be increased for greater aerodynamic efficiency. Combining winglets and supercritical wings could save 10 to 15 percent in fuel over that of current wide-body jets, NASA estimates. It may be possible to retrofit some current aircraft with these advanced wings in the early 1980's.

Active controls

Using motion sensors, on-board computers, and electrohydraulic devices to achieve active controls is yet another way to reduce fuel-robbing aerodynamic drag and buffeting.

Traditionally, airplanes have been designed to have "inherent static stability." This means a plane won't fly violently off course when a pilot removes his hands and feet from the controls. This stability, however, dictates an aircraft's tail size and some fuselage parts. The military, requiring superior speeds, range, and/or payloads, began compromising static stability for performance more than 20 years ago. The B-58 supersonic bomber, for instance, can be piloted at certain speeds and loads only with the aid of a sophisticated computer. Commercial airline operators have

been understandably reluctant to reduce static stability. But as their airliners have grown in size and weight, they have accepted boosted controls (the equivalent of power steering in your car), and a duplication of systems for maximum reliability.

A switch to active controls will put most movement of aircraft control surfaces in the hands of computers. As a result, several design changes will be possible: Smaller horizontal tails (less drag) and larger wing surfaces can be used. With the computer precisely distributing aircraft loads during maneuvers, less structural strength and weight will be necessary; this could result in a five-percent fuel saving.

Flying fibers

Composite materials, which are usually blends of boron or graphite fibers in a resin or aluminum matrix, may eventually trim aircraft weights by 25 percent, providing a 10- to 15-percent fuel saving. Used in aircraft for years, composites are lighter, stronger, and apparently longer-lasting than the metal parts they replace. So far, however, these super-tough materials have been used only for noncritical parts, such as rudders, panels, and spoilers—a fraction of total aircraft weight.

The aircraft industry moves cautiously about introducing these highly promising materials for primary-wing, fuselage, and tail structures. As yet, there is not enough data available on such critical questions as fatigue lifetime, maintenance, or exposure to weather and lightning strikes.

Better engines

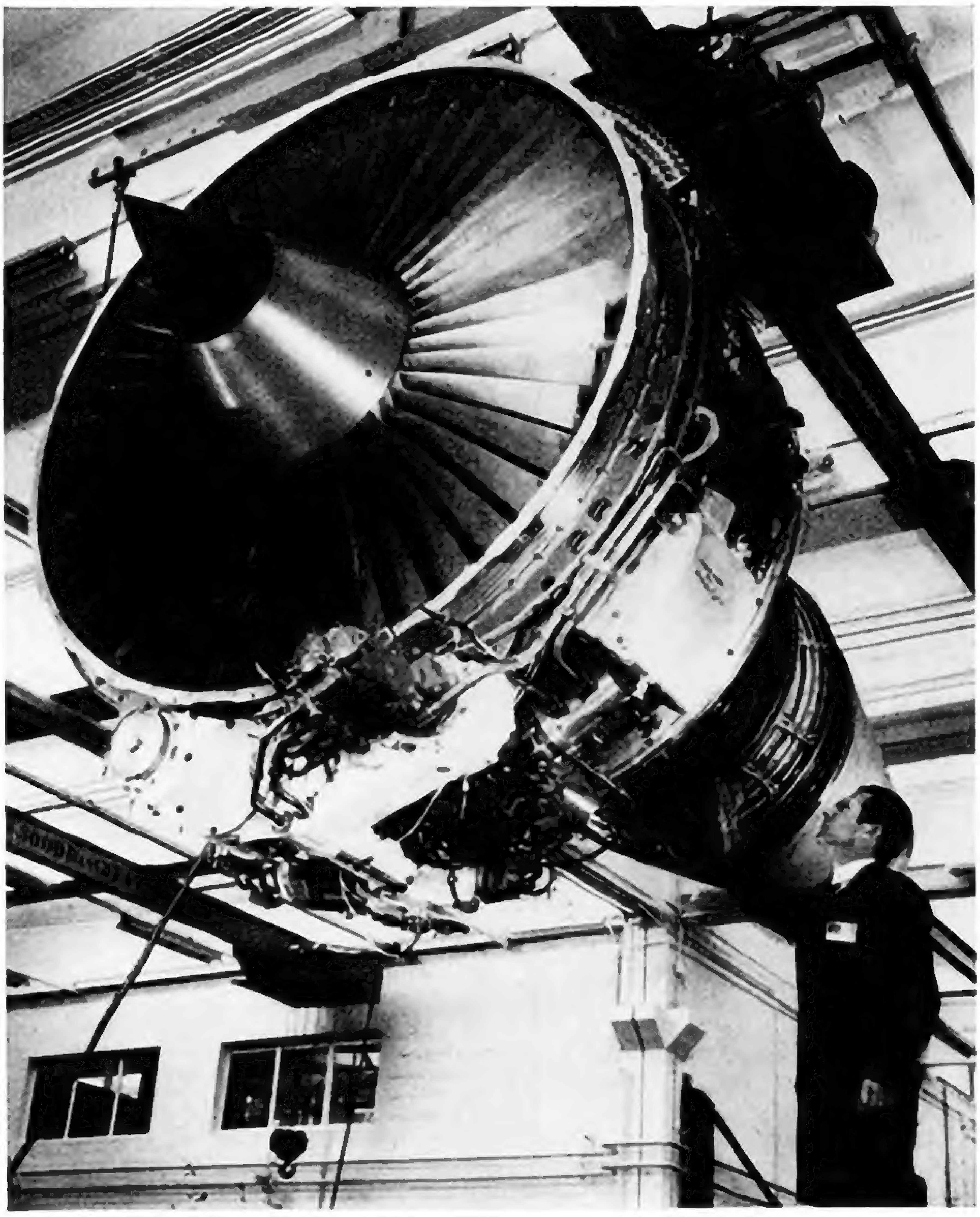
A wide spectrum of activities have been proposed to improve existing jet engines. Despite periodic maintenance, the performance and fuel efficiency of today's engines gradually deteriorate. The causes are well known: Compressors and turbine tips wear, ducts develop leaks, turbine blades erode, bearing seals wear, and fans pick up nicks. NASA has endorsed a plan to monitor engines now in service to determine how such wear can be minimized.

Other refinements, such as reducing the gaps between spinning and stationary parts, can aid fuel efficiency. Engineers are looking at sensor-monitored clearance controls to prevent catastrophic rubbing of engine components.

Enclosing engines in mechanical

[Continued on page 161]

Fuel-saving engines and planes that are already here



High-bypass-turbofan engine (top), under joint development by General Electric and France's SNECMA, uses 15 to 20 percent less fuel than low-bypass engines now powering short/medium-haul aircraft. The CFM56 turbofan (fan-jet) is in the 22,000-lb. (10-ton) thrust class. Pratt & Whitney's new JT10D is similar to the CFM56, but neither is yet in commercial use.

Boeing's new 747SP (above) has begun flights using 10 to 12 percent less fuel than its sister transport, the basic 747. The 747SP, the only transport capable of nonstop service between New York and Tokyo (6754 miles), is 47 ft. shorter and weighs from 38 to 58 tons less than the 747. The reduced weight, and a higher cruise altitude, means less work for the engines.

[Continued from page 83]

structures called mixers may boost fuel efficiency, too. Tests on models indicate that combining the core and duct streams of engines and discharging them through a common nozzle (see drawing on page 82) can increase propulsion efficiency and reduce noise. All advances—longer-lasting parts, tighter clearances, mixers—might be available by 1980.

All-new engines

A brand-new, advanced jet engine might enter service by 1990. This fuel-saving engine would incorporate earlier improvements, but operate at higher temperatures and pressures for improved thermodynamic efficiency. Lightweight composites for fan blades and the engine nacelle would improve fan efficiency and reduce overall engine weight. Also under development are materials for turbine blades that can sustain higher temperatures. NASA estimates these and other improvements for an advanced engine will result in 10- to 15-percent less fuel consumption.

In addition to these improvements on turbofan (fan-jet) engines, the NASA task force proposed we take another look at turboprop (prop-fan) airliners. Prop-fan aircraft, such as the Lockheed Electra, lost passenger appeal with the advent of the jet engine. Turboprop planes are about 200 mph slower than jets, and their operating altitude of 20,000 to 25,000 feet keeps them in uncomfortable turbulent air.

For fuel economy, however, the turboprop has always been inherently superior to the pure jet. The turboprop grips a large air mass and accelerates it only moderately. A jet accelerates a much smaller airflow to a much higher exhaust speed, wasting fuel as useless kinetic energy.

To make up for this energy loss, jet-engine designers gradually "reinvented the propeller" to develop the turbofan jet. They enlarged the diameter of the first few air-compressor stages, allowing additional air to be scooped up and led through a cylindrical duct around the engine. The air bypasses the higher-pressure compressor stages, combustion chambers, and gas turbines.

What results is the high-bypass-ratio turbofan engines that power all modern wide-body airliners. These engines are substantially more economical than the older pure jets and low-bypass-ratio turbofan engines still used in the bulk of our airline fleet.

Now engineers are reexamining the efficiency of a turboprop's huge propellers. For a long time it appeared that propellers had reached a technical limit with turboprop cruise speeds just over Mach 0.6. To create forward thrust, the propeller tip speed must considerably exceed the aircraft's cruise speed. This means that supersonic tip speeds are necessary for an airliner cruising at Mach 0.8. From an engineering and aerodynamic point of view, this was not attractive.

However, challenged by the new demand for a fuel-efficient airliner that can cruise at Mach 0.8 and a 30,000-foot altitude, the propeller people sharpened their pencils. Their proposal: multibladed, unshrouded prop-fan designs (see photo on page 81) that promise impressive fuel savings of about 20 percent over high-bypass-ratio turbofans.

Staying ahead

There is general agreement among manufacturers and operators of airlines that some combinations of these technological improvements should bring about a new breed of fuel-efficient aircraft. But who picks up the tab? The airlines, slowly recuperating from the impact of fuel-price hikes and a recession, can't offer manufacturers much hope for a massive reequipment of their fleets in the 1980's. And without assurance of sales, no manufacturer can invest huge sums for research and development.

As a result, it seems clear that unless Uncle Sam funds an aircraft fuel-efficiency program, nothing will happen. NASA's proposals would require about $670 million between now and 1985.

Today, some 78 percent of all the commercial transports flying throughout the world are U.S.-built. Last year, we exported $6 billion in civil aircraft and components. However, almost without exception, in every other highly industrialized country, development of commercial airlines is government-subsidized. If we fall behind in aviation technology, these competitors will grab the opportunity to offer a new breed of fuel-economical airliners to the fuel-starved world. The penalty for not spending several hundred million dollars during the next decade may be the loss of a multi-billion-dollar export market. PS